COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

June 1956

Aerial view of the Cromby Station, Philadelphia Electric Company, whose No. 2 unit employed tangent tube panel wall construction. See p. 46–49.

Ion Exchange Membranes for Water Conditioning ▸

The Cromby Story of Panel Construction ▸

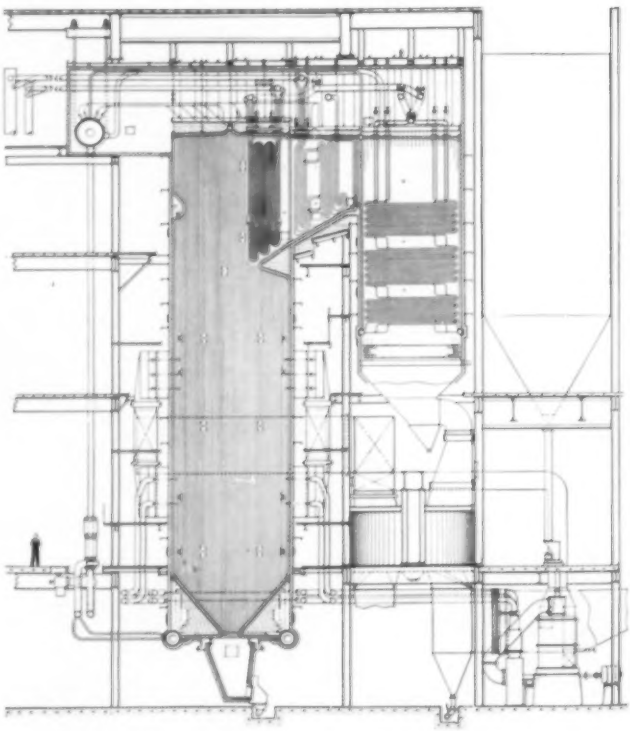
The Gas Turbine In Electric Power Generation ▸

Interim Steam Table for High Pressure Use ▸

MYSTIC STATION

C-E controlled circulation boilers

Boston Edison Company



The C-E Unit shown above is presently in process of fabrication for the Mystic Station of Boston Edison Company at Everett, Massachusetts. Jackson & Moreland are the Consulting Engineers.

This unit is designed to serve a 125,000 kw turbine-generator, operating at a throttle pressure of 1900 psi with a primary steam temperature of 1000 F, reheated to 1000 F.

It is of the controlled-circulation, radiant, reheat type with a divided furnace. The reheater surface is located between the primary and secondary superheater sections, and economizer surface is located below the rear superheater section. Regenerative type air heaters follow the economizer surface.

Pulverized coal firing is employed, using bowl mills and tilting, tangential burners. Arrangements are made for the use of oil as an alternate fuel as desired.

B-923

COMBUSTION ENGINEERING, INC.

Combustion Engineering Building
200 Madison Avenue, New York 16, N. Y.

STEAM GENERATING UNITS; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; HOME HEATING AND COOLING UNITS; DOMESTIC WATER HEATERS; SOIL PIPE

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 27 **No. 12**

June 1956

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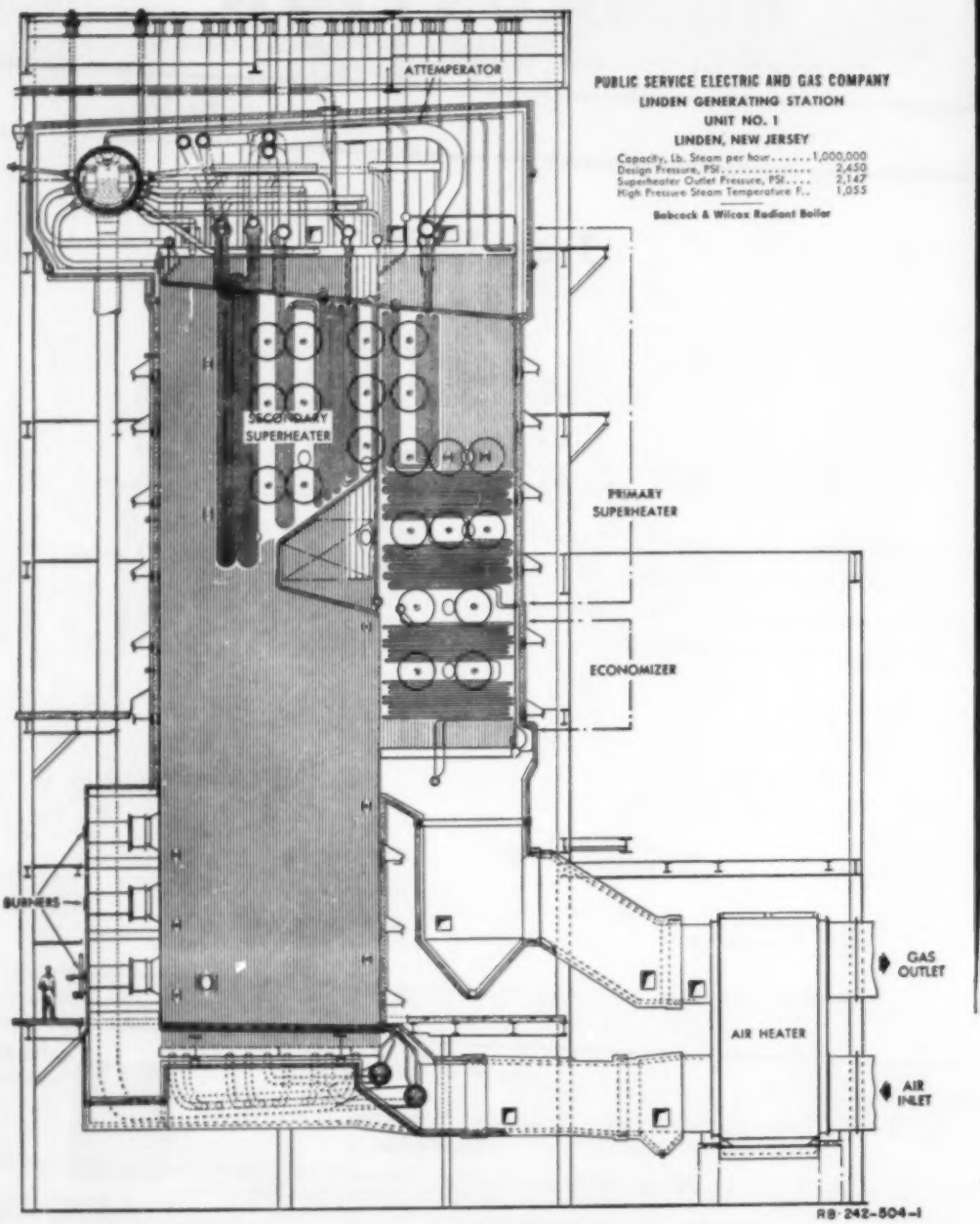
ATTEMPERATOR
PUBLIC SERVICE ELECTRIC AND GAS COMPANY
LINDEN GENERATING STATION
UNIT NO. 1
LINDEN, NEW JERSEY
Capacity, Lb. Steam per hour..... 1,000,000
Design Pressure, PSI..... 2,450
Superheater Outlet Pressure, PSI.... 2,147
High Pressure Steam Temperature F... 1,055
Babcock & Wilcox Radiant Boiler
SECONDARY SUPERHEATER
PRIMARY SUPERHEATER
ECONOMIZER
BURNERS
GAS OUTLET
AIR HEATER
AIR INLET
RB-242-504-I

It's Vulcan Automatic-Sequential at Linden Generating Station

Two of the retractable soot blowers at Sewaren Generating Station are Vulcan T-30 Long Retractables with 33 feet 2½ inches travel, the longest soot blowers built at the time they were installed. Their performance opened the door for a single installation on the new and larger twin-furnace boilers, with substantial overall savings to the user. It was a prime factor in the selection of Vulcan Automatic-Sequential Soot Blowing for the new Linden Generating Station of Public Service Electric and Gas Company.

This semi-outdoor station will have four Babcock & Wilcox radiant boilers with pressurized furnaces. Three of them—each with capacity of 1,000,000 pph at 2147 psig and 1055 F—make up Unit 1. Unit 2, a twin-furnace boiler with reheat, is rated at 1,900,000 pph at 2373 psig and 1100/1050 F.

The Vulcan T-30 Long Retractables to be installed on these units will have travels up to 33 feet. The T-30 Half-'Tracts will travel up to 16½ feet. Blowing medium: air. Drive: electric.

Effective, economical boiler cleaning is assured with the Vulcan Automatic-Sequential System. Any blower can be cut in or out of the automatic sequence—or blown individually from the panel. Control is at the operator's finger tips. And each blower reports its operation back to the central panel.

No matter what size your boilers—whether power or process—depend on Vulcan for optimum cleaning results.

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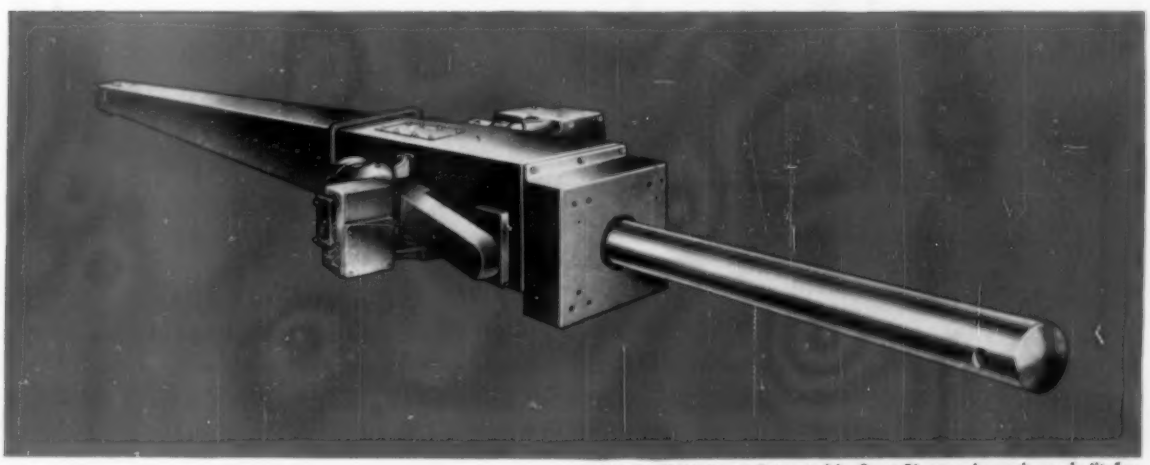
50th Anniversary BLAW-KNOX 1906-1956



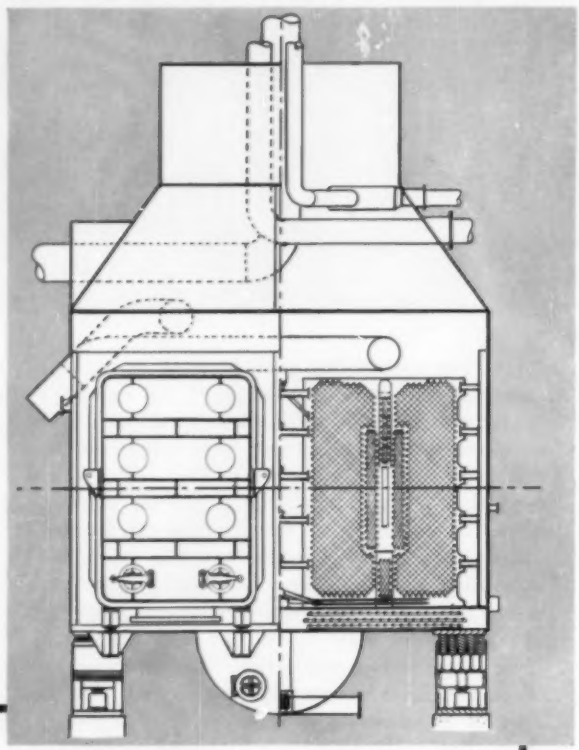
Vulcan T-30 Long Retractable Soot Blowers have been built for travels in excess of 35 feet to reach the most remote passes of steam generators. They are designed and built for long service life under the most rugged operating conditions.

Modern Dual Bank Condensers Pioneered by C. H. WHEELER

For 40 years C. H. Wheeler has led in steam power plant condenser design, from the first Dual Bank Condenser introduced to this country in 1916 to the most modern design for today's huge turbine-generators.

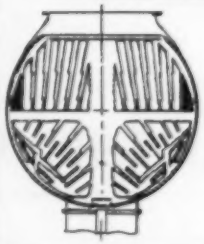
The latest C. H. Wheeler Dual Bank Condenser design for the largest metropolitan utility will provide 187,000 sq. ft. of surface to condense 1,600,000 pounds of steam per hour at 1.86 in. Hg. abs.

On the drawing boards now are new designs anticipating tomorrow's turbine requirements.

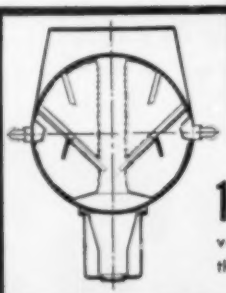


Modern Design Features..... 1956

1. **Specifically designed for today's larger, more efficient generating stations.**
2. **Adaptable to your station layout.**
3. **Lower pressure drop and higher vacuum. Additional steam lanes shorten path and resistance of steam travel.**
4. **"Zero" condensate temperature depression.**
5. **DEAERATION... 0.01 cc. per liter is attainable.**
6. **Airtight.**



1941 Additional steam lanes allowed steam to penetrate deeper. Further improvement in pressure drop. Better deaeration.



1923 Wider steam lane. Condensate temperatures corresponded to vacuum temperatures. Oxygen content less than 0.03 cc. per liter.

1916 An early C. H. Wheeler Dual Bank Condenser. Condensate temperatures approaching vacuum temperatures were achieved.

Let us tell you how our advanced designs will meet your operating requirements. Contact your local representative or

C. H. WHEELER MANUFACTURING CO., 19TH & LEHIGH, PHILADELPHIA 32, PA.

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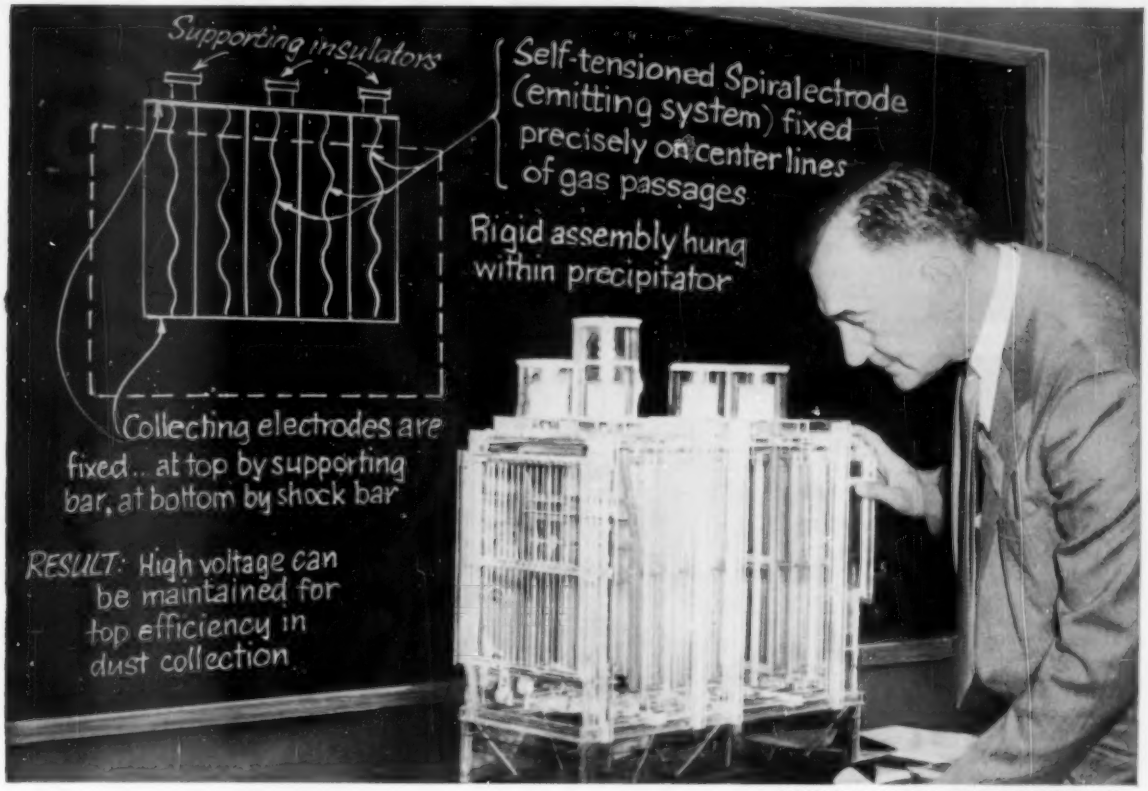
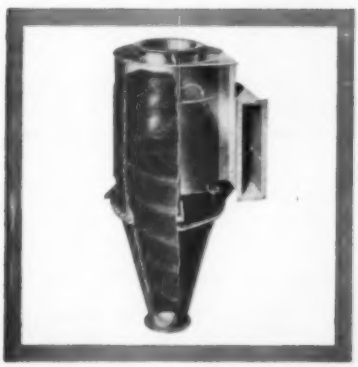
How fixed electrodes assure top efficiency in a Buell "SF" Precipitator

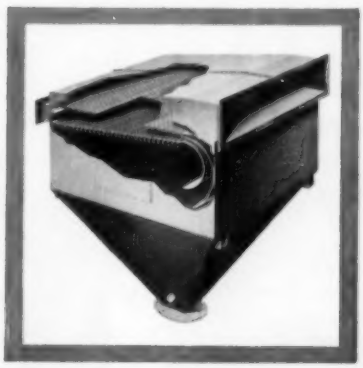

Supporting insulators
Self-tensioned Spiralectrode (emitting system) fixed precisely on center lines of gas passages
Rigid assembly hung within precipitator
Collecting electrodes are fixed.. at top by supporting bar, at bottom by shock bar
RESULT: High voltage can be maintained for top efficiency in dust collection

PHOTOGRAPH OF BUELL PLASTIC MODEL BY INDUSTRY & POWER



Buell Cyclones also assure top efficiency with large diameter design to eliminate clogging . . . and by harnessing double-eddy and putting it to work.

Even when high-resistivity dusts must be collected, top efficiency is guaranteed by the exclusive shape of Buell's Spiralectrodes—proved to give 50-100% greater emission than straight wires. Exclusive Continuous Cycle Rapping virtually eliminates maintenance by keeping electrodes constantly clean.



Buell's Low Resistance Fly Ash Collector combines top efficiency to meet present strictness, with low draft loss for natural or mechanical installations.

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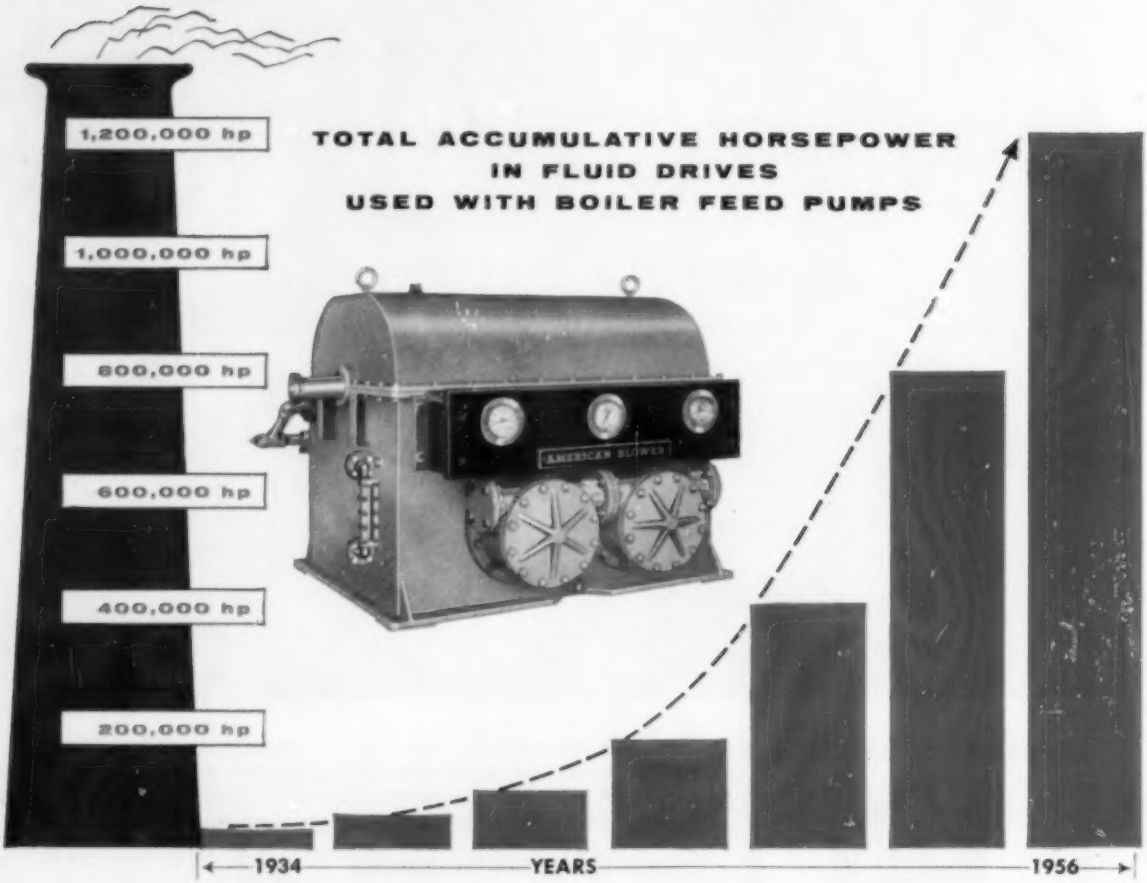


Accelerated industry-wide acceptance. Beginning in the late 1930's, demands for higher pump pressures resulted in the high-speed boiler feed pump. Consulting and utility engineers turned to Fluid Drive because of power savings from adjustable-speed operation. As a result, new quick-response, close-control Fluid Drives were developed specifically for feed-pump service. Rapid acceptance is shown on graph above. By 1957 there will be in operation in the U.S. close to 1,200,000 hp on feed pumps employing Gýrol Fluid Drives.

In the past ten years, about 250 new generating units (total capacity: 25 million kw) have employed Fluid Drive on the feedwater pumps. This number will jump sharply. For, present U.S. capacity of 100 million kw is expected to increase by 275% within 25 years.

TODAY, Gýrol Fluid Drives save power in plants using conventional fuels, and tomorrow will figure prominently in atomic-powered systems. Stepless speed control of Fluid Drives also saves power on mechanical draft fans; simplifies motors and starting.

Drive for feed pump control!

Here's how power plants of all sizes are using American Blower Gýrol Fluid Drive to prolong equipment life, reduce pressure, save power!

To make more net generating capacity available to consumer lines, more and more power plants of all sizes are turning to Gýrol Fluid Drive to transmit power from the prime mover to the pump.

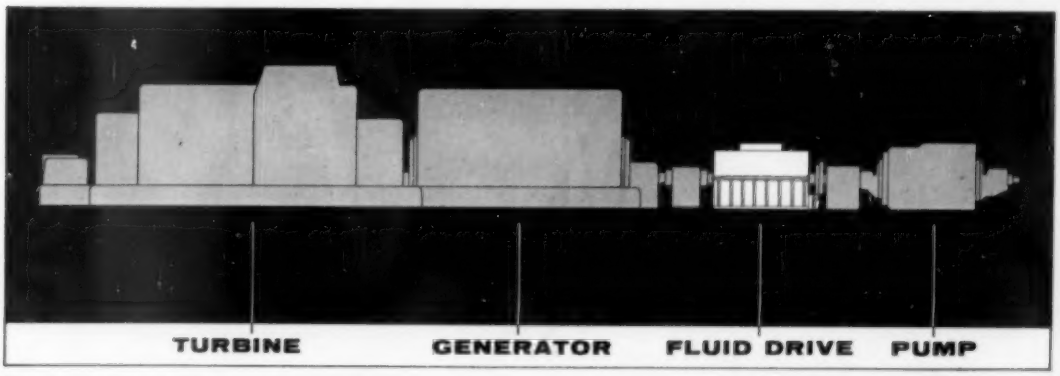
For, of all power-plant auxiliaries, the boiler feed pump and its prime mover consume the greatest single segment of invested power: an average 2.5%. And, with higher steam pressures and temperatures, estimates of 4% to 6% are being discussed for the immediate future—indicating the necessity for power-saving adjustable-speed pump control through the use of Fluid Drive.

The reason for the big swing to Gýrol Fluid Drive lies in the inherent advantages it offers. The use of Gýrol Fluid Drive results in a substantial savings in power, since on present-day, modern high-pressure boiler installations it permits reduction in pressure by use of the Gýrol Fluid Drive's adjustable-speed feature. This reduction in pressure often amounts to 500 lbs. or more.

Through the use of Fluid Drive, the boiler feed pump need only be driven at speed necessary to overcome system friction and boiler pressure. This results in lower pump operating speeds; lower duty on piping, high-pressure heaters, and valves—reducing maintenance and extending equipment life.

In the power-plant industry, Fluid Drive is renowned for its flexibility of control. The narrow range of speed over which a boiler feed pump must operate requires fine increments of speed adjustment, coupled with the need for quick response. The stepless, infinitely adjustable speed control of Gýrol Fluid Drive, together with its rapid response, more than meets this requirement. The Gýrol Fluid Drive has been engineered and designed to be conveniently linked to standard boiler feed water automatic control systems.

In your plans for power expansion, it will pay you to talk to an American Blower engineer. His knowledge of the application of Gýrol Fluid Drives, and American Blower's many other power-plant products, can prove invaluable to you. Just contact your nearest branch office, or write to us direct. American Blower Corporation, Detroit 32, Michigan. In Canada: Canadian Sirocco Company, Ltd., Windsor, Ontario.



THINGS TO COME. World's largest boiler feed pump—now being built for Consolidated Edison Co. of New York, Inc.—employs a new concept of drive: the main generator steam turbine. Twice as large as any feed pump now in existence, pump is rated at 12,000 hp, with power transmitted through an American Blower Type VS, Class 6 Gýrol Fluid Drive. For full details on American Blower equipment —Fluid Drives, Mechanical Draft Fans, Fly Ash Precipitators, Dust Collectors, Heavy Duty Steam Coils—contact our nearest branch.

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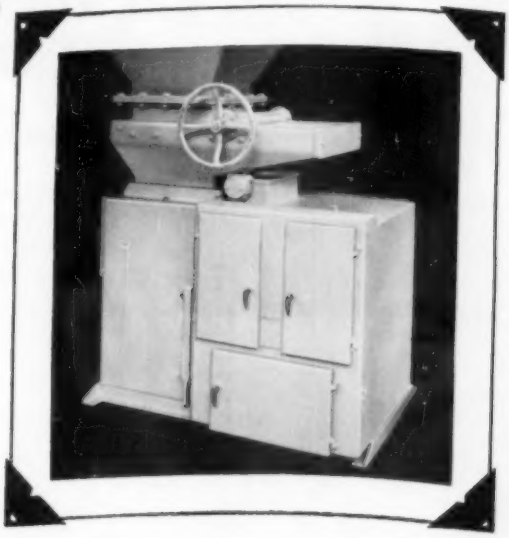
It's BRAND SPANKING NEW!

BABY'S NAME *Model 50 S-E-Co Coal Scale*

BABY'S PHOTO



BABY'S WEIGHT *Accurate and dependable*

DISTINGUISHING FEATURES *24" square inlet opening - vertical skirts - no baffles - unrestricted 24" flow of coal throughout. Endless feeder belt carried on idlers - capable of moving full column of coal.*

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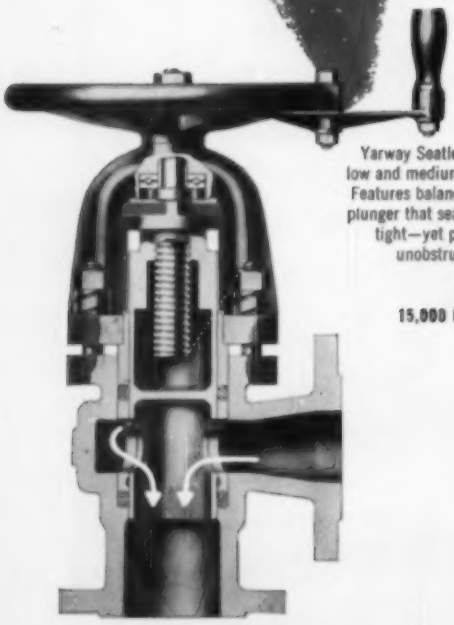
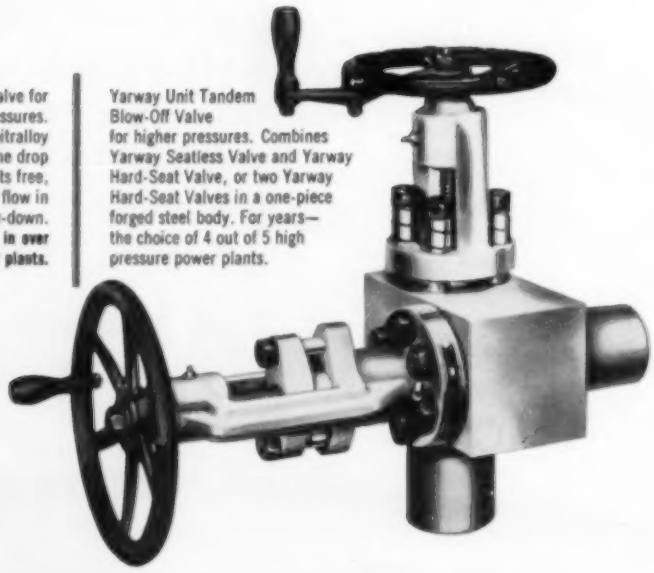
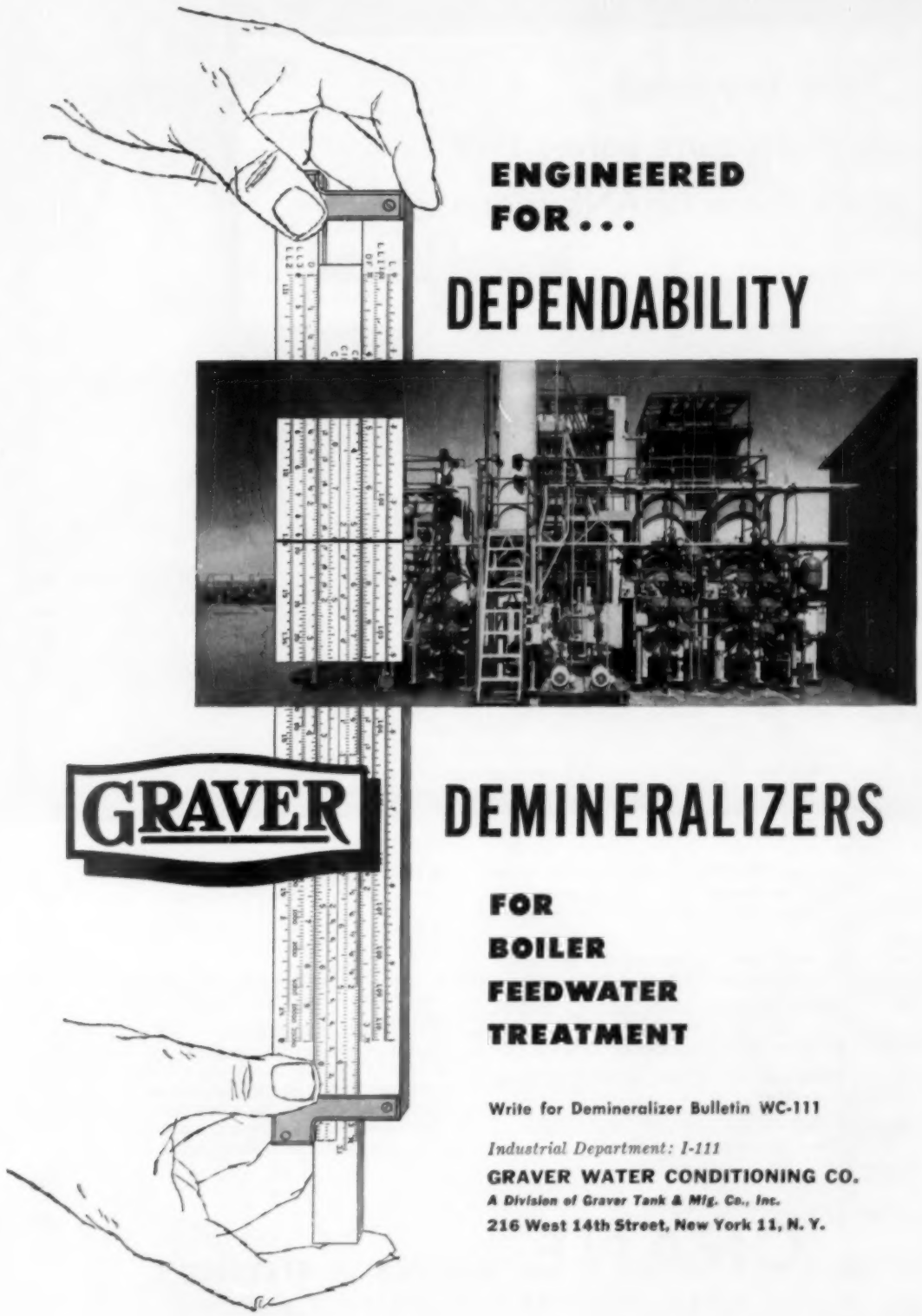


Yarway Seatless valve for low and medium pressures. Features balanced nitralloy plunger that seals line drop tight—yet permits free, unobstructed flow in blow-down. **Used in over 15,000 boiler plants.**



Yarway Unit Tandem Blow-Off Valve for higher pressures. Combines Yarway Seatless Valve and Yarway Hard-Seat Valve, or two Yarway Hard-Seat Valves in a one-piece forged steel body. For years—the choice of 4 out of 5 high pressure power plants.

YARWAY blow-off valves



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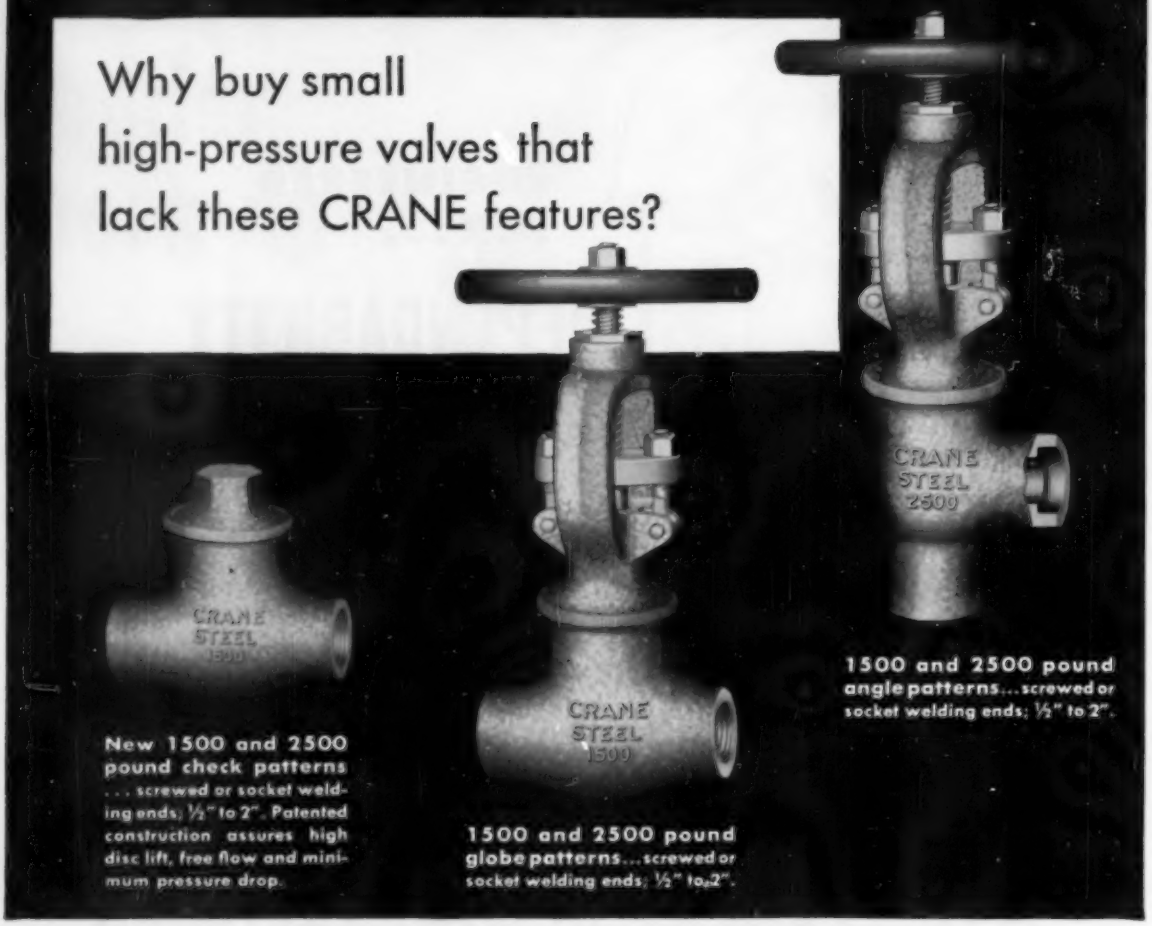
Why buy small high-pressure valves that lack these CRANE features?



New 1500 and 2500 pound check patterns . . . screwed or socket welding ends; ½" to 2". Patented construction assures high disc lift, free flow and minimum pressure drop.

1500 and 2500 pound globe patterns... screwed or socket welding ends; ½" to 2".

1500 and 2500 pound angle patterns... screwed or socket welding ends; ½" to 2".

When you buy CRANE Lip-Seal Bonnet Valves . . . designed exclusively for high pressure/high temperature power plant service . . . you are assured of:

- lip-seal welds that are laid on flat surfaces—needn't be chipped out or burned out;
- easy dismantling and reassembly—bonnet screws out after weld is *ground away*—makes inside of valves entirely accessible;
- bonnet threads are chrome plated to prevent galling or seizing;
- stems that do not bind or gall—because of CRANE's exclusive ball-joint glands;
- easy access to stuffing box—swing-type gland eye-bolts swing free of yoke area, can't be lost;
- a more rigid swivel disc-stem connection that minimizes vibration;
- each size valve is a separate design for proper proportion—another CRANE exclusive.

These features assure better small valve performance with important maintenance savings. Use Crane Lip-Seal on main and auxiliary steam . . . on boiler feed and blowdown lines . . . on drips, drains, by-passes, etc. Ask your local Crane Representative for circular AD-1902 on these valves, or write to address below for a copy.

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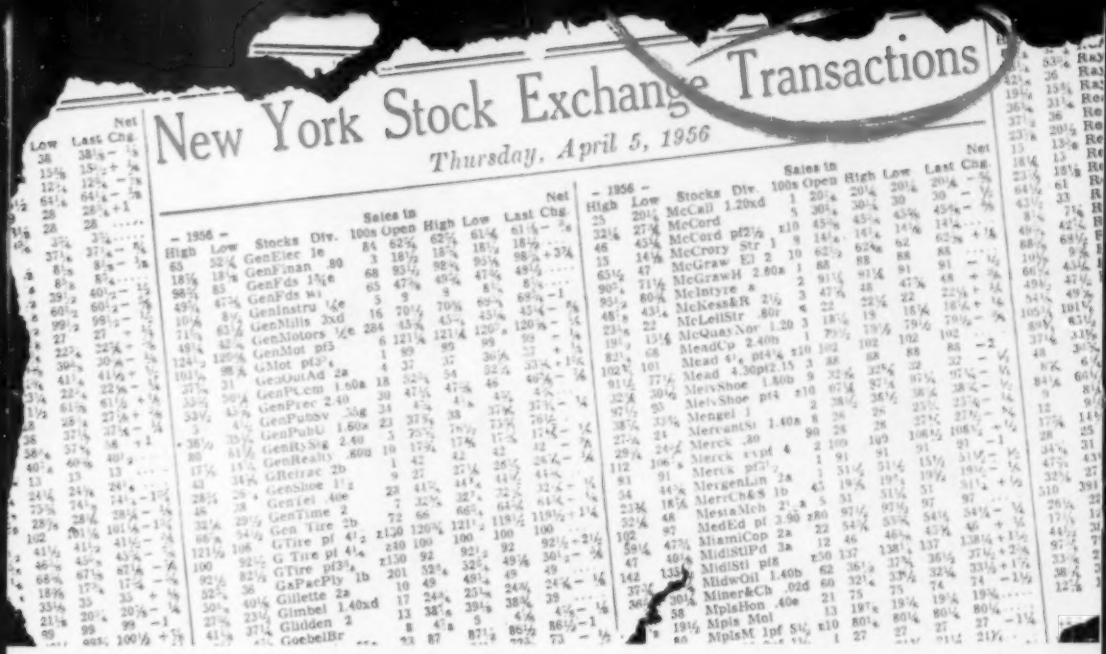
PIPE • KITCHENS • PLUMBING • HEATING

Since 1855—Crane Co., General Offices: Chicago 5, Ill. Branches and Wholesalers Serving All Areas



New York Stock Exchange Transactions

Thursday, April 5, 1956

– 1956 – High	Low	Stocks	Div.	Sales in 100s	Open	High	Low	Last	Net Chg.
65	52¼	GenElec	1e	84	62⅝	62⅝	61¼	61½	– ⅝
85	67⅝	GenFinan	.80	3	18½	18⅝	93¼	98⅜	+ 3⅞
18⅝	18⅛	GenFds	1⅛e	68	93½	98⅝	47⅛	48½	
98⅝	85	GenFds	wi	65	47⅜	49⅝	8¼	8⅝	– 1
47⅝	47⅜	GenInstru	⅛e	5	9	9	70½	69⅝	– ⅝
10⅛	8½	GenMills	2xd	16	70½	45¾	45¼	45¼	– ⅛
71½	63½	GenMotors	⅛e	284	45⅜	121¼	120⅞	120⅜	– ⅛
48¼	42⅜	GenMot	pf3	6	121¾	95	99	99	+ ¼
124⅛	120⅛	GMot	pf3¾	1	99	37	30⅜	32	+ ⅛
101¾	98⅜	GenOutAd	2a	4	37	54	32¾	33¾	+ 1⅛
37⅞	31	GenPcm	1.60a	18	52⅜	47⅝	46	46⅜	– ¼
55½	50¼	GenPrec	2.40	39	47⅝	4⅛	4¼	4¼	
53½	43⅜	GenPubSv	.35g	34	4¾	33	32⅜	32½	– ⅛
3	4½	GenPubU	1.60a	23	33⅜	76½	73⅜	76½	
38½	35⅞	GenRity	2.40	3	75⅝	17⅝	17⅝	17⅝	– ⅛
80	61½	GenRealty	.80g	10	17¾	42	42	42	– ⅞
17⅝	15⅞	GRefrac	2b	1	42	27⅛	28½	26¾	– 1⅛
43	34⅜	Genshoe	1½	9	27	44¾	44¾	44¾	
28½	26¼	Gen'el	.40e	22	41⅝	32⅞	32⅝	32⅝	– ¼
48	38	GenTime	2	7	32⅝	66¾	64½	64¾	– 1¼
32⅛	29½	Gen Tire	2b	72	66	121½	119½	119½	+ 1¼
66⅜	54⅜	GTire pf	4½	z130	120⅝	100	100	100	
121½	106	G Tire pf	4¼	z80	100	92½	92	92	+ 2½
100	92½	GTire pf	3¾	z130	92	52¾	49¼	49¼	– ⅛
92½	82⅝	GxPacPly	1b	201	52¾	49¼	49	49	
52⅝	36	Gillette	2a	10	49	25¼	24¾	24¾	– ⅛
30⅝	40⅛	Gimbel	1.40xd	17	24¾	39	38¾	39	
27⅝	23½	Glidden	2	13	38¼	43⅛	43⅛	43⅛	– ⅛
41⅛	37¼	GoebelBr		8	47⅛	5	4⅛	86½	– 1
				93	87	87½	86½	73	– ½

NONE . . . without brick!

That's right—NONE! No sales . . . no profits . . . no financial page . . . no industry. *You* would have nothing to make . . . buy . . . sell . . . or transport were it not for refractory brick.

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Refractories, you see, are born in many shapes and of many compositions to do a variety of jobs. It's brick and high-temperature refractory mortars, plastics, castables, and bulk products that prison temperatures of thousands of degrees for industry.

General Refractories, making and distributing exactly the right refractory to industries everywhere, maintains the world's largest refractories laboratory and draws resources from all over the globe.

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Monolithic furnace linings of GREFCO plastic firebrick are economical and will provide long uninterrupted service. Three high quality mixes are available for various furnace conditions with a selection of well engineered refractory and high temperature alloy metal anchors for various combinations and thicknesses.

GREFCO plastics are manufactured at three strategically located plants in Pennsylvania, Missouri and Georgia. Stocks are maintained for prompt truck delivery at all company warehouses and dealers in principal cities.

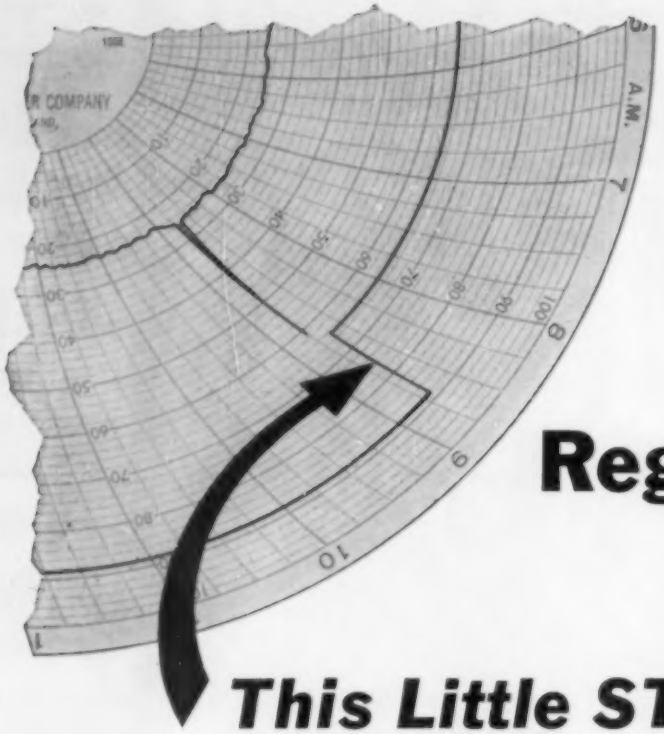
When you specify GREFCO you are assured of quality second to none. The world's finest and best equipped refractory laboratory is constantly developing new products and improving old ones. District laboratories constantly check raw materials and finished products. GREFCO places great emphasis on uniform high quality.

SUPER BRIKRAM MIX-G—a super duty quality plastic firebrick with a special binder which provides an airset when material is air dried. Provides high strength throughout the entire thickness of the wall or arch.

SUPER BRIKRAM—a plastic firebrick of super duty quality for furnace linings where conditions warrant the use of super duty quality. Has excellent resistance to spalling and high temperatures.

BRIKRAM—a plastic firebrick of high duty quality. Excellent for patching or complete furnace linings where conditions do not require a super duty quality refractory.

GENERAL REFRACTORIES



Bothered by Smoke Control Regulations?

This Little STEP Could Save You Money

The step you see is a positive measurement of the length of time of excessive smoke *accurate to within 6 seconds.*

This record, combined On The Same 24-Hour Chart with a continuous measurement of Smoke Density, gives *a complete permanent record of performance*—visual proof, in an unbeatable pair, of your efforts to comply with the Air Pollution Control Ordinances.

Now you can have such a record—and at a very moderate cost—with the new *Bailey Running Time Recorder* combined with the Bailey Smoke Density Recorder.

You owe it to yourself to investigate this unique pair, exclusive with Bailey and designed to aid you in complying with the Smoke Control Requirements of your community. P37-1

BAILEY METER COMPANY

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INSTRUMENTS AND CONTROLS

For Power And Process

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EASTERN GAS AND FUEL ASSOCIATES

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GET GREATER SAFETY AT LOWER COST...

CHOOSE THE TYPE 1511

CONSOLIDATED SAFETY VALVE

TYPE 1511 CAST IRON BODY SAFETY VALVE
SIZES: 1½" through 6". **PRESSURES:** up to 250 psi. **TEMPERATURES:** up to 450° F. All sizes except 6" available with oversize flanges.

Maximum safety comes first in power engineering. But lower initial equipment investment and lower maintenance costs are also essential factors. The Type 1511 Consolidated Safety Valve gives you all three. It is an all-purpose safety valve, expressly designed for steam generator service, yet costs less than other makes for the same service.

Among the many advantages of the Type 1511 are:

1	Positive tightness because the seat is precision lapped to optical flatness.
2	Stable operation and uniform blowdown control because the spring is exposed.
3	Better alignment, easier blowdown adjustment and finer performance because the valve has an integral, double-guided combination adjusting ring and disc guide.
4	Cuts the cost per pound of steam discharged because maximum capacity is designed into minimum flange size. The size and/or number of safety valve nozzles required on any boiler are reduced.
5	Saves space – requires less headroom and smaller discharge piping.

The Type 1511 Consolidated Safety Valve is made in a full range of sizes and orifices. Write for Bulletin 730 and learn the complete story of the greater safety and economy of the Type 1511.

In Canada: *Manning, Maxwell & Moore of Canada, Ltd., Galt, Ontario.*

CONSOLIDATED SAFETY VALVES

A product of **MANNING, MAXWELL & MOORE, INC.** STRATFORD, CONN.

MAKERS OF 'AMERICAN' INDUSTRIAL INSTRUMENTS, 'ASHCROFT' GAUGES, CONSOLIDATED SAFETY VALVES, 'AMERICAN-MICROSEN' INDUSTRIAL ELECTRONIC INSTRUMENTS, *Stratford, Conn.* 'HANCOCK' VALVES, *Watertown, Mass.* 'CONSOLIDATED' SAFETY RELIEF VALVES, *Tulsa, Okla.* AIRCRAFT CONTROL PRODUCTS, *Danbury & Stratford, Conn. and Inglewood, Calif.* "SHAW-BOX" AND 'LOAD LIFTER' CRANES, 'BUDGIT' AND 'LOAD LIFTER' HOISTS AND OTHER LIFTING SPECIALTIES, *Muskegon, Mich.*

The Power Plant Engineer Said: "I WOULDN'T KNOW..."

INQUIRING REPORTER: So you use Nalco System water treatment ... How often are your boilers turbined?

ENGINEER: I wouldn't know—only worked here seven years. *

* You recognize the Engineer's answer as a twist on the old one about *How-often-do-you-get-a-raise-around-here.* Our excuse for bringing it up is that the engineer's answer applies to hundreds of plants using Nalco water treatment. New plants, starting boilers from scratch with Nalco, report years on line, *billions* of pounds of steam generated in boilers that have *never* been turbined ... and probably never will be. Older plants, where turbining was as routine as checking the draft gauges, now open boilers only to show the inspectors.

These Nalco *results* can quite possibly be duplicated in your plant, regardless of the kind or severity of your water treatment problems ... or the size of your operation. Write or phone, now, for a fast start toward permanent water treatment security.

NATIONAL ALUMINATE CORPORATION

6234 West 66th Place • Chicago 38, Illinois

Telephone: POrtsmouth 7-7240

In Canada: Alchem Limited, Burlington, Ontario

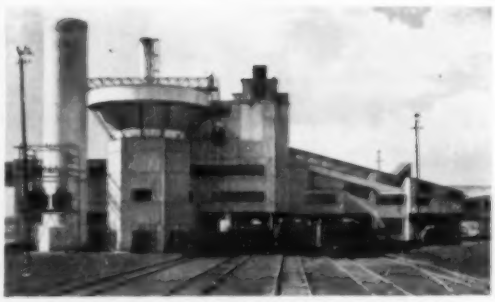
THE *Nalco*® SYSTEM ... Serving Industry through Practical Applied Science

Why pay freight for ashes and water ?

You're buying BTU's—not bulk—when you specify free-burning, low ash BUCKHORN from Bell & Zoller's Southern Illinois fields. Every ton is *superwashed* to remove non-burning debris . . . heat dried to a low, even moisture content before loading. Extra BTU's replace the waste removed from every ton you receive.

BUCKHORN makes a perfect "prescription coal" too—firm-structured, carefully screened and blended to your exact burning requirements.

It's shipped via Illinois Central, CB & Q, C & EI, Missouri Pacific routes. Order BUCKHORN through your nearest Bell & Zoller office.



Buckhorn Mine with modern washer, Williamson County, Illinois. Daily capacity: 5,000 tons No. 6 seam coal.

Bell & Zoller Coal Company

70 YEARS OF SERVICE TO COAL USERS

BELL BUILDING, CHICAGO 1, ILLINOIS

Detroit • New York • St. Louis • Minneapolis
Omaha • Milwaukee • Louisville • Washington, D.C.
Terre Haute, Ind. • Mount Hope, W.Va.

Set your sights on an HD-6G

for top performance
for top dependability
for top versatility

2¼-yd Coal bucket (shown), 1½-yd Standard bucket, **55** belt hp **19,600** lb

in coal handling

. . . plus all these exclusive on-the-job advantages important to both owners and operators . . .

Allis-Chalmers long-life diesel engine — power that handles tractor and bucket demands with ease.

Heavy welded-steel shovel side frames and low stabilizer — provide greater strength, low center of gravity, outstanding visibility.

Full-flow filtering — filters oil three ways, provides long-life protection for hydraulic system.

Six truck-wheel stability — almost 7 ft of track on the ground for superior balance.

Two-position 1½-yd or 2¼-yd buckets — handle big loads efficiently in either loose or hard-packed coal.

All-steel, box-A main frame — soaks up shock loads, protects the entire power train.

One-piece steering clutch and final drive housing — line-bored for true alignment of shafts and gears.

Straddle-mounted final drives— with bearings on both sides of gears to maintain correct gear tooth alignment.

Simplified lubrication (including 1,000-hour lubrication intervals on truck wheels, idlers and support rollers) provides extra working time.

Unit construction —makes service easier, faster. Major units can be removed without disturbing adjacent assemblies.

Plus husky wrap-around radiator guard . . . simplified piping . . . heavy-duty truck frames . . . heavy-duty, roller-bearing truck wheels . . . matchless control . . . and the convenience of 24-volt direct electric starting.

Check the complete service program offered by your Allis-Chalmers construction machinery dealer. His factory-trained servicemen, factory-approved facilities, and stocks of True Original Parts keep your equipment operating properly . . . provide the kind of service that saves you money. See him soon; he'll be glad to show you an HD-6G at work.

ALLIS-CHALMERS, CONSTRUCTION MACHINERY DIVISION, MILWAUKEE 1, WISCONSIN

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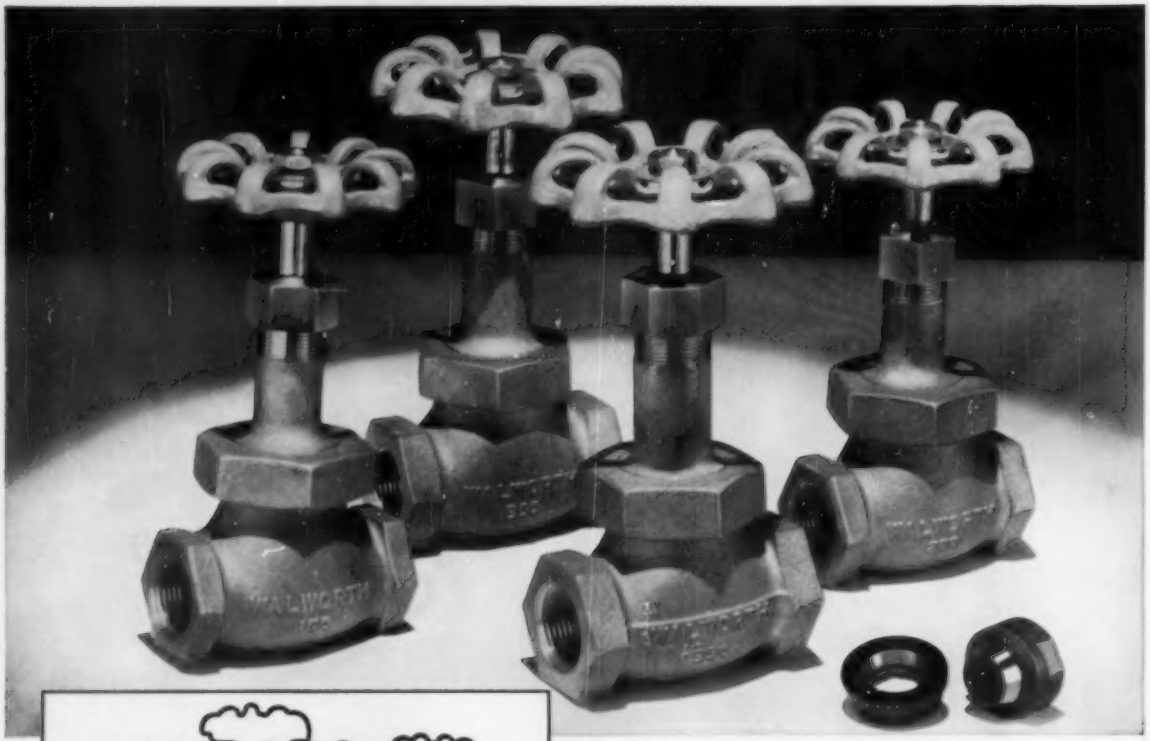

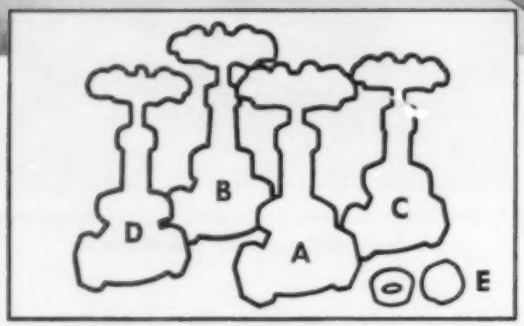

A — No. 225P.....350 WSP 550F, 1000 WOG
B — No. 260P.....300 WSP 550F, 600 WOG
C — No. 245P.....200 WSP 550F, 400 WOG
D — No. 237P.....150 WSP 500F, 300 WOG
E — "500 Brinell" Stainless Steel Plug Type Seat and Disc

Walworth offers four lines of Bronze Globe Valves with stainless steel, plug-type seats and discs. Advantages of these valves include:

• **Stainless Steel Plug-Type Seats and Discs,** heat-treated to a minimum of 500 Brinell hardness reduces wire-drawing to a minimum. Seats and Discs are machined and fitted simultaneously, assuring perfect mating.

• **Deep Stuffing Boxes with Glands** are fitted with reinforced, molded packing. Valves can be repacked under pressure when fully opened.

For Longer Bronze Valve Life . . .

"500 BRINELL" PLUG-TYPE STAINLESS STEEL SEATS AND DISCS

150 lb. 200 lb. 300 lb. 350 lb.

• **Oversize Stems,** made of high tensile strength silicon-bronze, assure long life.

• **Rugged Body Hexes,** are flat on top; do not interfere with wrench gripping body-to-bonnet union ring connection.

• **Bodies,** made of Composition M bronze (ASTM B61), have ample wall thickness to provide high safety factor.

• **Patented Handwheels** are air-cooled and designed with a "finger-fit grip." Makes turning easy even when wearing greasy gloves.

• **Identification Plates** secured by lock-washer under stem nut, show Figure Number of valves and make re-ordering sure and easy.

FOR COMPLETE INFORMATION, SEE YOUR WALWORTH DISTRIBUTOR OR WRITE FOR ILLUSTRATED CIRCULAR

WALWORTH

60 East 42nd Street, New York 17, New York

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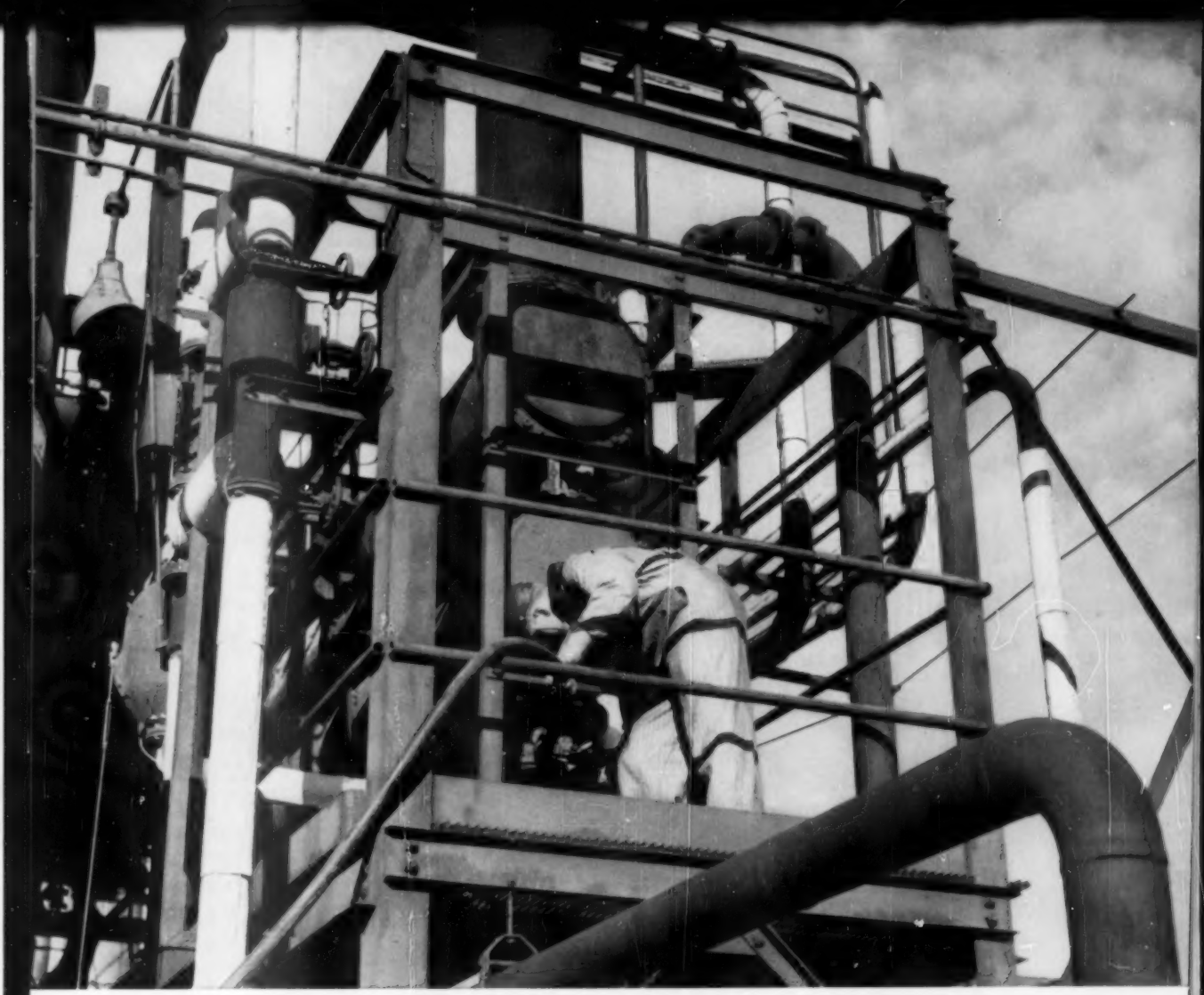


There's too much at stake —clean it right

Chemical cleaning involves costly equipment and often work stoppages. It's a job for experts. Let Dowell protect that equipment and keep production losses to a minimum when you have scale or sludge problems.

In over 15 years our trained engineers have serviced virtually every kind of equipment in plants, mills and refineries throughout industry. In fact, Dowell has cleaned over 10,000 boilers alone!

This experience means lower costs to you—in more thorough work, restored efficiency and less production loss.

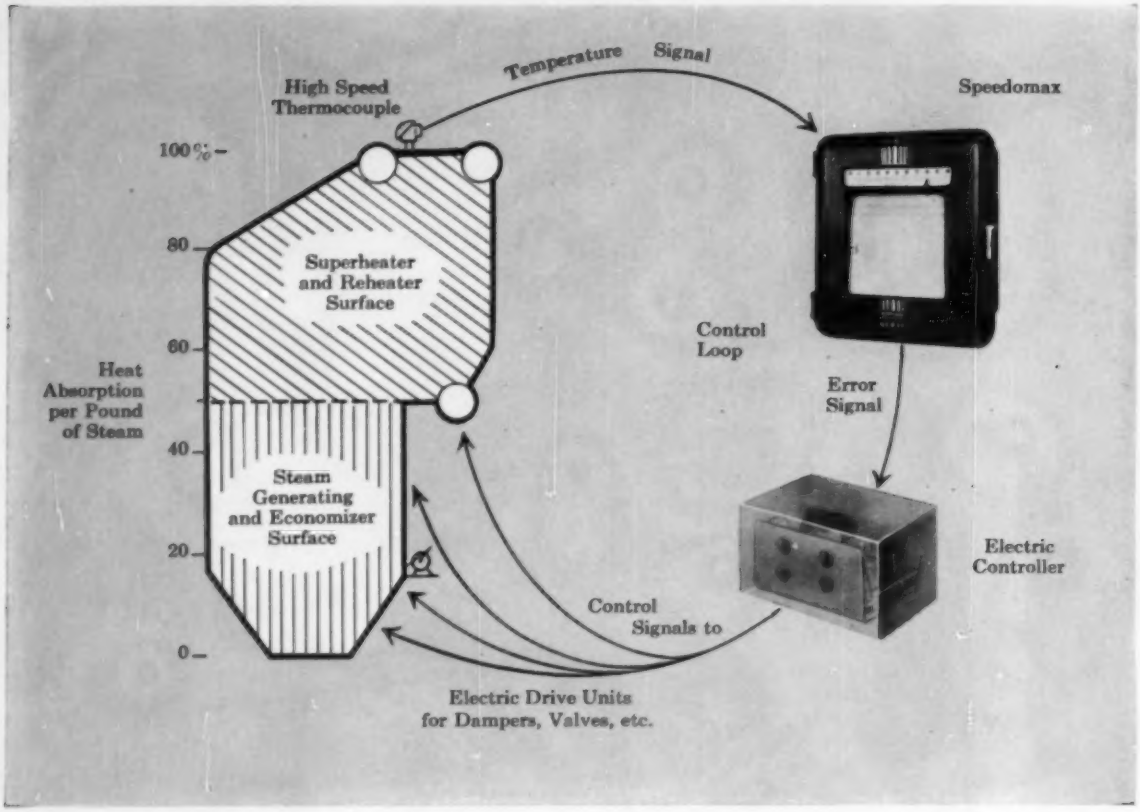
Furthermore, Dowell engineers know you value the safety of your men and equipment. Dowell uses only the latest safety equipment and techniques to eliminate hazards and accidents. Our engineers work closely with your safety personnel to establish the safest possible working procedures.

Call the nearest of more than 165 Dowell offices. An experienced engineer will be glad to talk over and help you with your cleaning problems any time — at no obligation. Or write Dowell Incorporated, Tulsa 1, Oklahoma, Dept. F-25.

chemical cleaning service for industry

DOWELL

A SERVICE SUBSIDIARY OF THE DOW CHEMICAL COMPANY



THIS STEAM TEMPERATURE CONTROL

puts heat where you want it!

● Because superheater and reheater surfaces of many modern boilers receive 50 per cent—or more—of the heat liberated, the proper control of heat distribution is a governing factor in attaining efficiency. Steam temperature control, by regulating this distribution, maintains optimum Btu /lb of steam, and helps prevent overheating of the metal surfaces.

L&N's *all-electric* steam temperature control solves this critical problem effectively over a wide range of load and furnace conditions. The basic components of the control are as follows:

High Speed Thermocouples—Especially designed to provide accurate sensing of temperature, with a response several times as fast as non-specialized thermocouples.

Speedomax Recorders—Provide sensitivity, accuracy and proved reliability of measurement; with auxiliary alarms and control safeguards specified for this very exacting service.

Versatile Electric Controller—With control actions–proportional, reset and rate–tailored to meet not only the requirements of a single operating condition (such as control of a valve), but also of *added* operating conditions (as when control must be transferred to dampers or other devices). Preliminary control action, initiated from changes in boiler air flow, is similarly tailored for each operating condition. Reheat unit control systems are coordinated to prevent one temperature control from interacting with or upsetting the other.

Electric Drive Units—Provide dependable, positive positioning of dampers, valves, burners, etc. under conditions both normal and adverse.

Let our engineers work with you to arrive at an effective solution of your superheat—reheat control problems. Please address us at 4972 Stenton Ave., Philadelphia 44, Pa.

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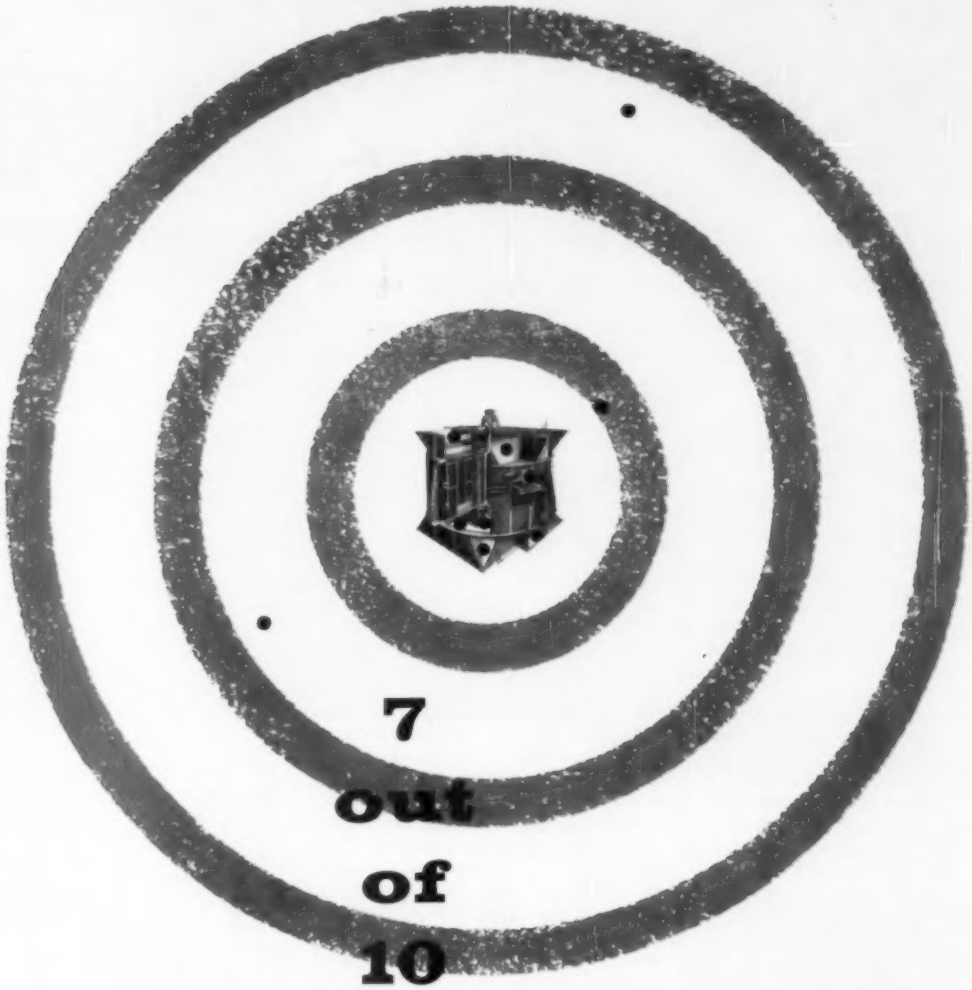
instruments *automatic controls* • *furnaces*



air preheater installations are Ljungstrom®

Advantages of the Ljungstrom Air Preheater

- Size for size, recovers more heat than any other type.
- Reduces fuel consumption. Permits use of lower-grade fuels. Increases boiler output and reliability.
- Eliminates cold spots...keeps corrosion to a minimum.
- Easier, faster to clean and maintain.
- Requires far less supporting steel and is quickly erected.

MINIMUM CORROSION is an important reason. There are no cold spots in a Ljungstrom. Temperature is uniform on all heating surfaces—corrosion-causing condensation is reduced.

For all the facts, send now for a free copy of our 38-page manual.

The Air Preheater Corporation 60 East 42nd Street, New York 17, N. Y.

Hall Industrial Water Report

VOLUME 4 JUNE 1956 NUMBER 3

Slime—a Low Life That Rates High as the Cause of Corrosion, Deposit Formation, and Offensive Odors

Control of slime in cooling and process water depends on proper diagnosis of the problem and use of effective disinfectants.

A Difficult Odor Problem

Every Monday morning when the air conditioning system was started following Sunday shutdown, one of Pittsburgh's largest department stores was embarrassed by a strong musty odor. This usually disappeared before the store opened at noon, but when the dehumidifiers were shut down several days for repair, the odor was so distressing and persistent that Hall Laboratories was called on for help.

Hall engineer, R. A. Danesi, recognized that aerobic microorganisms washed from the air filters into the spray unit pans were responsible for the odor. When units were shut down, there was insufficient aeration to keep the microorganisms alive and they died and rotted.

Danesi immediately fed an odorless disinfectant to the pans. The obnoxious odor did not disappear fast enough, however, and it was necessary to use a strong oxidizing agent as a temporary measure.

A sample of the slime was brought to the laboratory for identification. The report confirmed the presence of protozoa and bacteria which continue to live and multiply so long as they receive an adequate supply of air. Since equipment shutdowns could not be avoided, control would have to be accomplished by effective disinfection to prevent accumulation of slime.

Feeding of Calgon Algaecide® and regular water washing of the units eliminated the odor for a time. When the odor returned, another disinfectant was fed. This also worked for a time. But these were tough little bugs which built up immunity to either material when it was used continuously.

Alternate feeding of the two chemicals every two weeks proved to be too much for them, however. This procedure solved the problem and the store now has odorless operation of the treated units.

Labor Costs Effectively Reduced

Fouling of the evaporative condensers used to cool ammonia for process refrigeration was so severe in a rubber manufacturing plant serviced by Hall's Boston office that the units had to be hand-cleaned every week end to insure continuity of operation through the following week.

Investigation revealed that slime was retarding heat transfer. This condition was aggravated because the slime also trapped air-borne talc to such an extent that deposits completely filled the spaces between some of the condenser tubes. Head pressure on the ammonia compressors was continuously at its upper limit and was high enough at times to shut them off.

Treatment was started with 50 ppm of calcium hypochlorite to kill the growth and the sytem was flushed to get rid of the dead slime-forming organisms. Thereafter, calcium hypochlorite was added in sufficient amount every shift to give 1 ppm residual chlorine one hour after treatment. 5 to 10 ppm of Calgon T® was also added continuously to the water for control of corrosion.

Head pressure on the ammonia compressors shortly decreased to 50 psi below the former high, reflecting improved heat transfer in the evaporative condensers. Manual week end cleaning of the condensers is no longer required. Regular operators are able to take care of feeding chemicals so that there has been no increase in labor cost.

Formaldehyde to the Rescue

A Michigan laboratory engaged in the manufacture of pharmaceuticals, culture media, and related items had a very complicated problem of slime growth. The circulating water from the cooling tower was used in the vacuum pan system where much of the proteinaceous material was concentrated as part of the manufacturing process. The tower water acted as a barometric condenser so that material boiled out of the vacuum pans was caught in the water and traveled through the cooling tower water circuit. Slime development was so great that the slats and interdecking were completely filled and water cascaded in sheets down through the central part of the tower.

Chlorophenate concentrations of 50 to 100 ppm had been found to be ineffective in controlling the slime-forming organisms. Hall engineer, E. S. Stewart, tried calcium hypochlorite. He experienced fantastic chlorine demand and the development of large amounts of foam. The foaming was controlled easily with Hagan C-1 Antifoam®, but the tremendous chlorine demand rendered the procedure impractical.

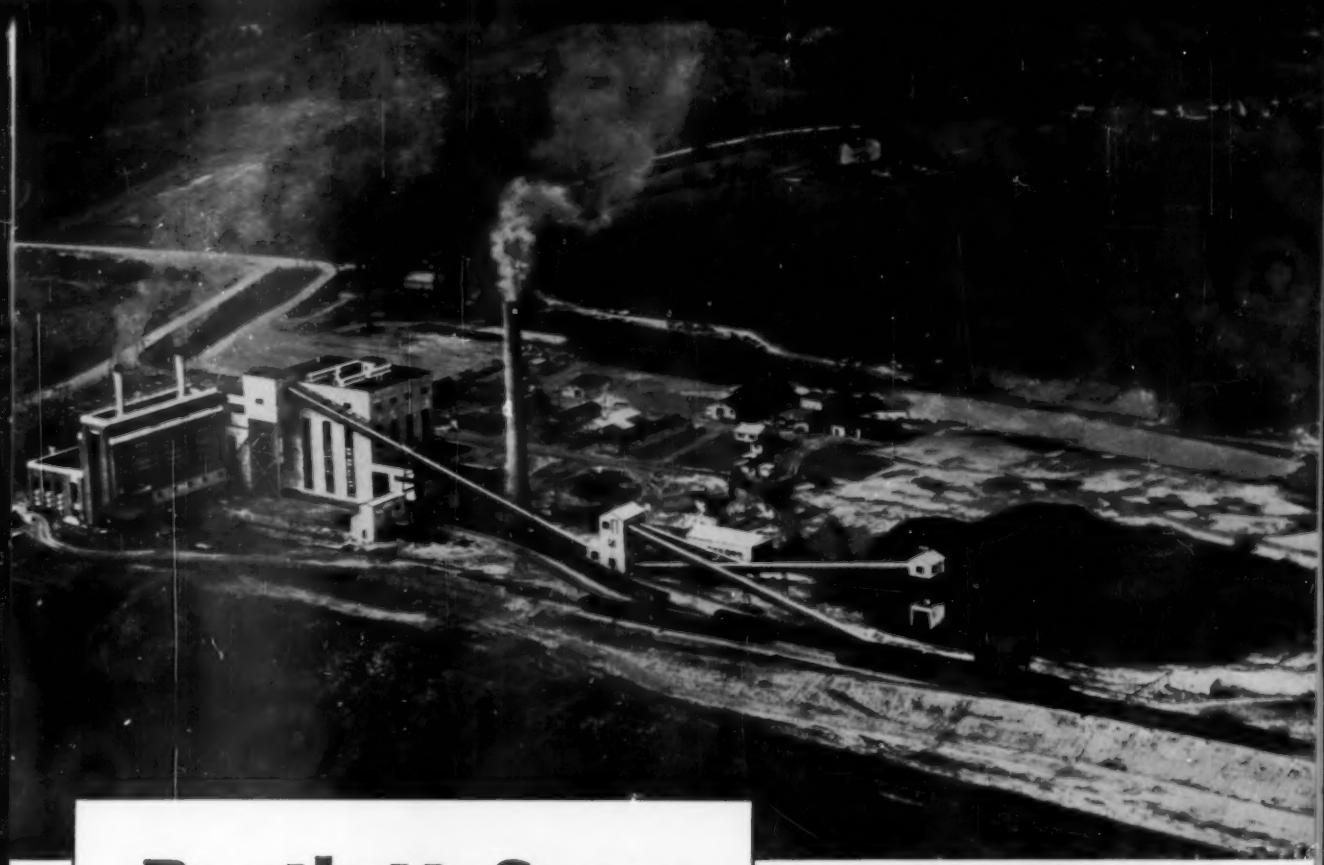
Stewart tried formaldehyde as a disinfectant. At a concentration of 40 ppm, this chemical has inhibited slime development sufficiently that plugging of the tower is prevented. Further improvement in conditioning can now be accomplished by proceeding on an orderly rather than an emergency basis.

Industrial Water Problems Require Special Handling

There are no "stock answers" to industrial water problems. For information write, wire or call Hall Laboratories, Inc., Hagan Building, Pittsburgh 30, Pa.

Water is your industry's most important raw material. Use it wisely.

Hall Laboratories, Inc.—Consultants on Procurement, Treatment, Use and Disposal of Industrial Water



General View of Bremo Plant
Virginia Electric and Power Co.
Stone and Webster Engineering Corp.
Consulting Engineers

Bartlett-Snow coal handling at *Bremo*

● The illustration above shows both the original building and the new addition of this 60,000 KW plant. All equipment including the track hopper, duplex feeder, 1326′ of belt conveyors, the 70′ dust tight flight distributor in the new addition, and the 111′ distributing belt and belt driven tripper in the original building were detailed and fabricated in our shops and installed by us to Stone and Webster's specifications. For maximum efficiency and fixed unit responsibility, let the Bartlett-Snow coal handling engineers, work with you on your next job.

View of Dust Tight Flight Conveyor
Distributing Coal to Bunkers (New Addition)

View of Belt and Belt Driven Tripper
Distributing Coal to Bunkers (Old Building)

DESIGNERS ENGINEERS

BARTLETT-SNOW
CLEVELAND 5, OHIO

FABRICATORS ERECTORS

"Builders of Equipment for People You Know"

Built on an Unassailable Foundation

PACIFIC®
BOILER FEED PUMPS

PARTS EITHER CIRCULAR OR CYLINDRICAL

CARE AND PRECISION DURING MANUFACTURE & ASSEMBLY

UNITIZED INTERNAL ASSEMBLY AMPLY SUPPORTED · FREE TO EXPAND

PRECISION BALANCING FREE FROM VIBRATION IN OPERATION

EXPANDS WITHOUT DESTROYING ALIGNMENT OR CLEARANCE BETWEEN PARTS

DESIGN CLEARANCES STAY PUT CONTINUOUS SMOOTH OPERATION

METAL-TO-METAL POSITIVE SEAL

RING TYPE PRESSURE JOINTS SEALED TIGHT—NOT OPENED BY INTERNAL PRESSURE

HIGH EFFICIENCY LONG USE LIFE · MINIMUM MAINTENANCE

GOOD ENGINEERING AND DESIGN SUPREME QUALITY MATERIALS

CAREFUL, PRECISE WORKMANSHIP

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Pacific Boiler Feed Pumps
Write for Bulletin 122.

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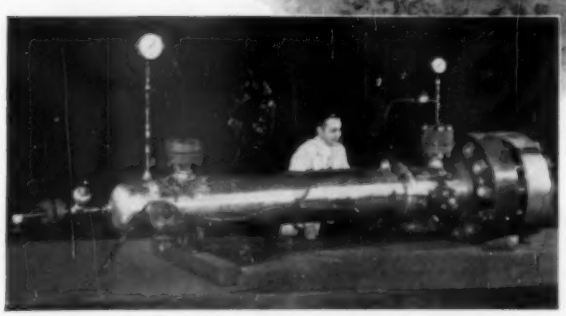

P. P. & E. produced the first piping installations for marine and stationary nuclear power plants. Our facilities are complete—metallurgical research, laboratory service, engineering, shop fabrication, testing, and field erection. We have fabricated stainless steel piping for power and process industries since the middle 1920's.

since 1903
fabricators of
power and process piping
for these industries...

Electric Generating
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PP-10

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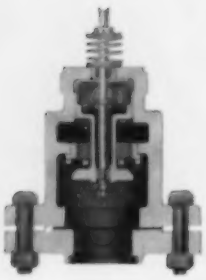
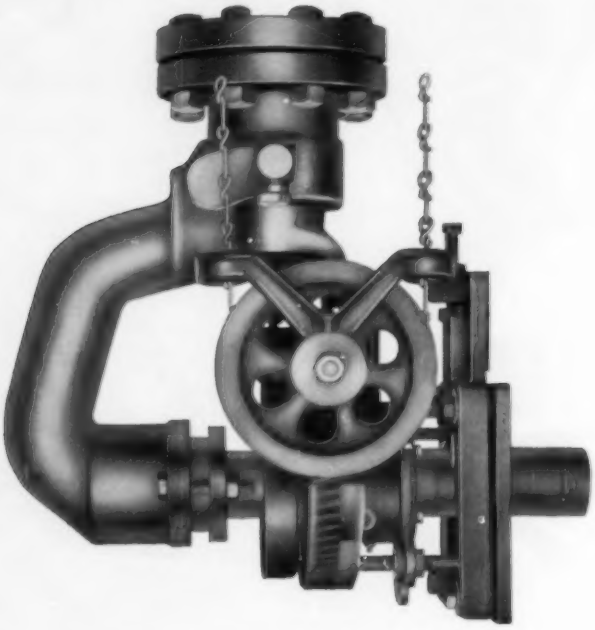
BAYER

STEPS UP BOILER PERFORMANCE

DISTINCTLY DIFFERENT



Bayer Balanced Valves are famous for their long life and continued tightness



Bayer Single Chain Balanced Valve Soot Cleaner

WITH THE Bayer Balanced Valve Soot Cleaner the balancing chamber above the piston disc impounds steam when the valve closes, thus relieving valve parts from shock. The valves remain *steam tight* because the dashpot action causes the valve to seat gently. Unbalanced valves close with a hammer stroke and soon become leaky.

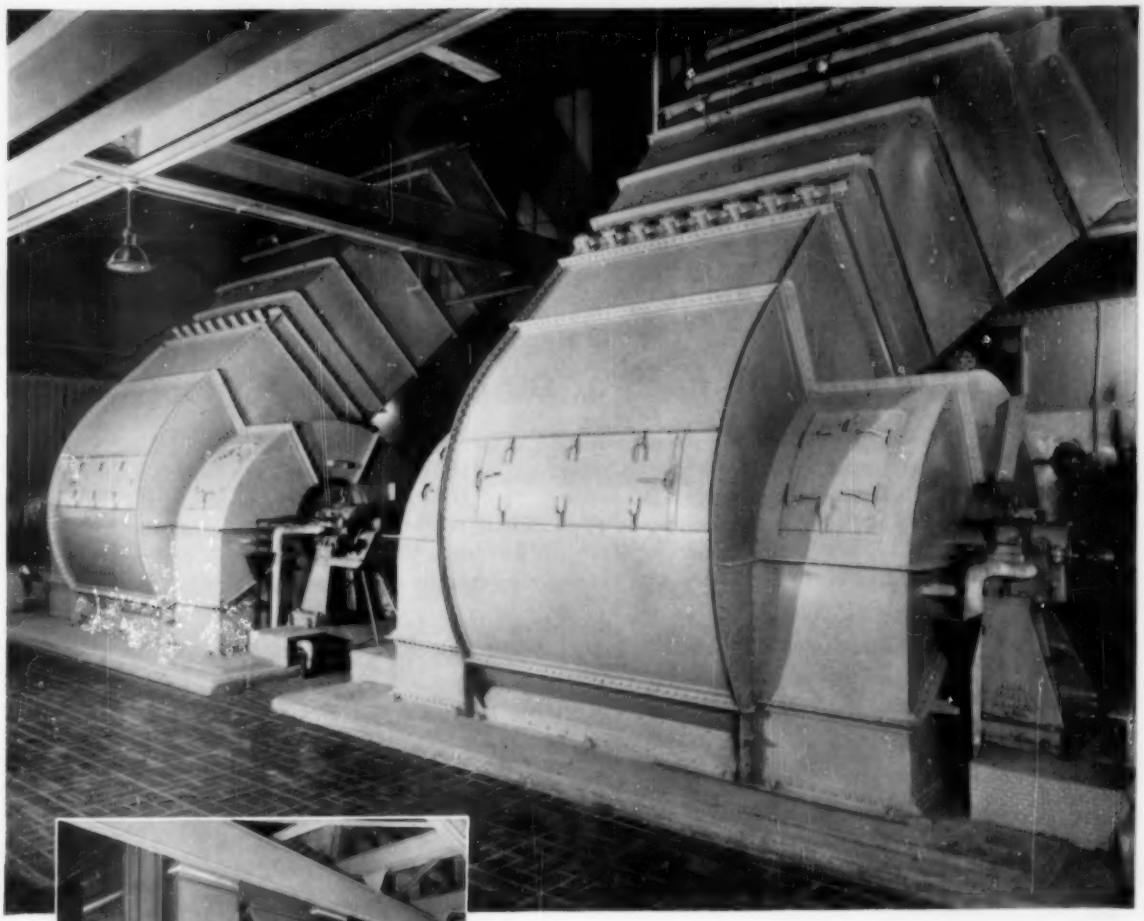
When stationary elements are used the Bayer stationary balanced valve head may be furnished. Thus all the cleaning elements of the entire soot cleaner system can be controlled by the Bayer quick-opening Balanced valves. This gives a uniform or standard valve controlled system and in addition, when high pressures require a reduction in pressure *at each individual element* this Balanced valve unit, whether used with a stationary or a revolving element, can be fitted with an integral orifice plate valve.

Piping connections can be kept in the same plane and undesirable bends or fittings avoided when the Bayer Balanced Valve is installed with both stationary and revolving elements.

Valve parts are standard and interchangeable and when high pressure heads are fitted with orifice plate regulating valves these parts are also interchangeable.

THE BAYER COMPANY

SAINT LOUIS, MISSOURI, U. S. A.



Top Photo: Two "Buffalo" Forced Draft Fans recently installed in a large Ohio Valley utility station. "Buffalo" outlet damper control.

Two "Buffalo" Induced Draft Fans in the same new power plant. These ruggedly built fans have both the endurance and high efficiency to provide the greatest draft economy.

another modern utility station using "Buffalo" fans

"Buffalo" Mechanical Draft Fans have always been the choice of leading utility stations, as well as industrial plants, because of their famous "Q" Factor* construction — the "Q" Factor of bonus strength, accessibility and outstanding efficiency. Their low maintenance costs and their economy of driving power combine to give the lowest possible draft costs. Thousands of "Buffalo" installations are proof of it.

And, to match the exact conditions under which you plan to operate, "Buffalo" offers you a complete choice of tested and proven blade designs — backward curve, our new deep-bite airfoil wheel, radial and forward curve blades.

Assure this important part of your power production—specify "Buffalo". Write for Bulletin 3750 or contact your nearby factory-trained "Buffalo" Engineering Representative.

*The "Q" Factor — the built-in Quality which provides trouble-free satisfaction and long life.

BUFFALO FORGE COMPANY

BUFFALO, NEW YORK

Canadian Blower & Forge Co., Ltd., Kitchener, Ont.

"Buffalo"

VENTILATING AIR CLEANING AIR TEMPERING INDUCED DRAFT EXHAUSTING FORCED DRAFT COOLING HEATING PRESSURE BLOWING

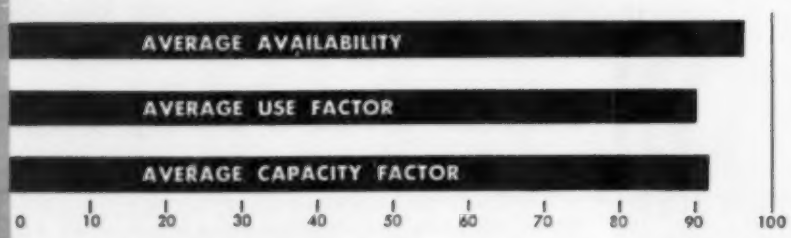
How much is

Operating Record of 99 C-E Reheat Boilers

There are 183 C-E Postwar Reheat Boilers in service, under construction or on order. These boilers represent an aggregate capacity of 22,273,000 kilowatts . . . an average of 122,000 kw per unit.

The first of these boilers was placed in service in September, 1949. By the end of 1955, ninety-nine units were "on the line." The combined service of these 99 units represents a period equivalent to 224 boiler years. Significant data concerning them are summarized below.

Total Capacity — kw	10,932,000
Average Capacity per Unit — kw	110,000
Total Boiler Time — hours	1,974,640
Total Boiler Time — years	224



DISTRIBUTION OF TOTAL OUTAGE	PERCENT
Inspection	2.34%
Boiler • Superheater • Reheater Economizer • Air Heater • Desuperheater — Fuel Burning Equipment	0.96%
(Auxiliary Equipment) Valves • Fans • Soot Blowers • Miscellaneous	0.66%
Total	3.96%

availability worth?

Many of today's high-capacity, highly efficient generating units have a "worth value" reaching into many thousands of dollars for each day that they are unavailable for any reason.

The steady trend to higher unit capacities, pressures and temperatures has, of course, but one principal objective – higher efficiency . . . lower BTU rate per kilowatt-hour.

And it only pays off when the unit is "on the line"

That's no news to the utility industry but the highly satisfactory composite performance record of the 99 C-E postwar reheat units now in service . . . shown on the opposite page . . . has a very direct bearing on the subject.

It adds up to this – the primary objective in the design and construction of C-E reheat boilers is to assure maximum lifetime availability. How well that objective is being achieved is defined by the record.

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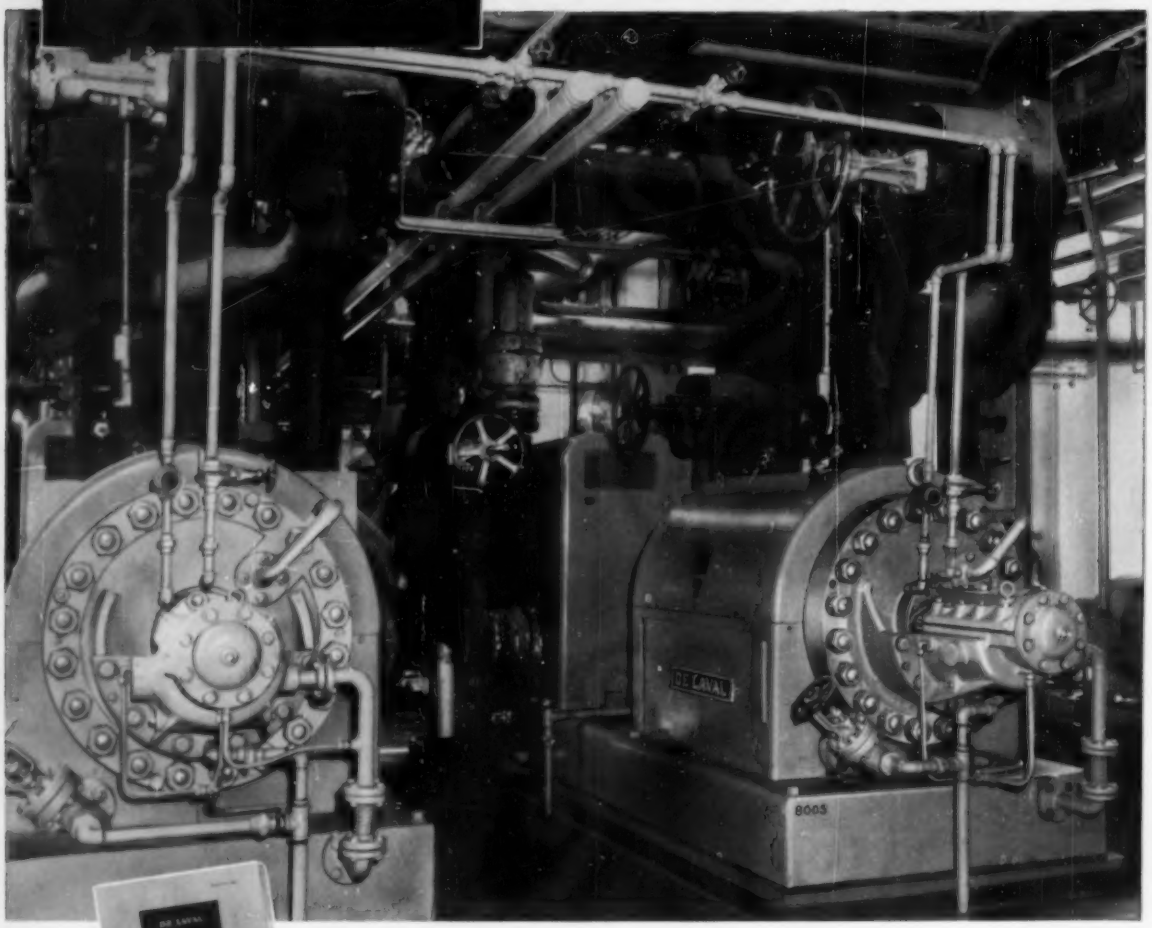

Bulletin contains helpful data

Bulletin 1506 on the De Laval barrel type boiler feed pump covers all major design points... has cross-section cutaway illustration for easy reference. Write for your copy.

Here's additional proof of De Laval reliability on the line in the Bogalusa, La. plant of the Gaylord Container Corporation. These two De Laval barrel type boiler feed pumps are both driven by De Laval MCP turbines operating at 850 psi, with steam temperature at 825 F.

• De Laval barrel type boiler feed pumps are widely used by industrial plants and public utilities. They operate at pressures up to 5,500 psi. These units offer many important design advantages, such as double volute diaphragm, individual diaphragm bolting, positive sealing between suction and discharge chamber and bare shaft construction. Their dependability is proven by year-in, year-out service.

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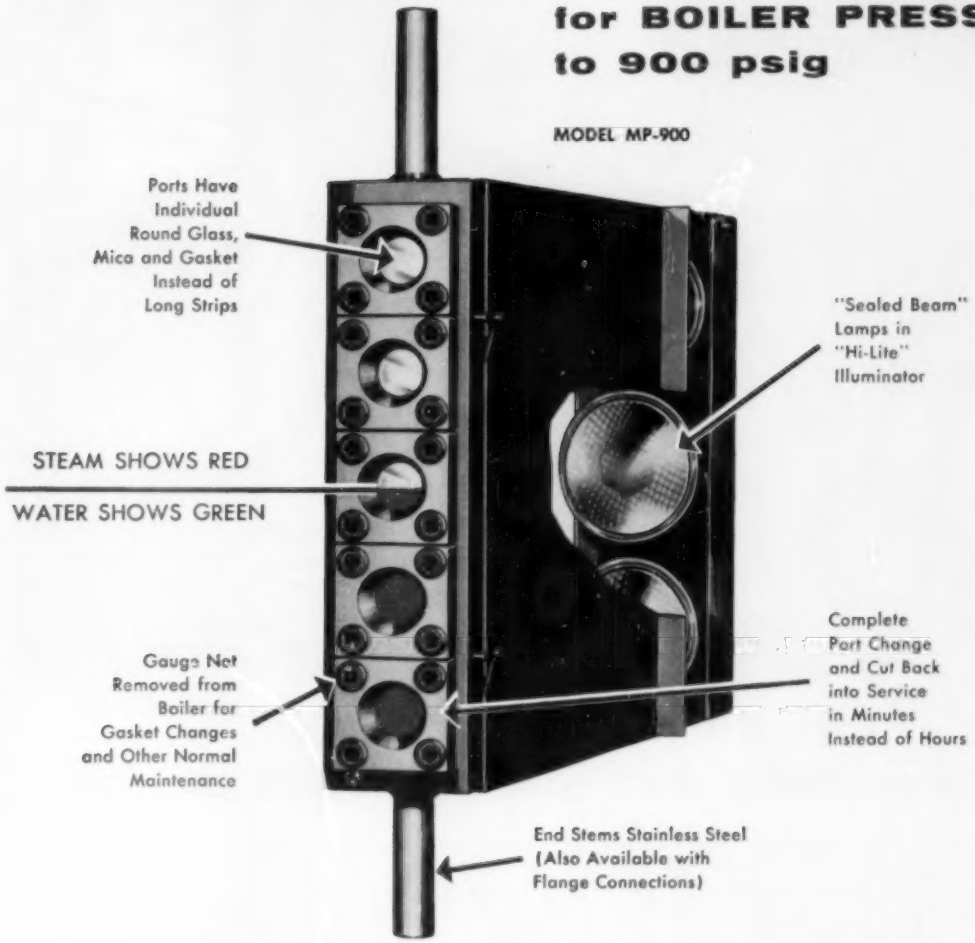
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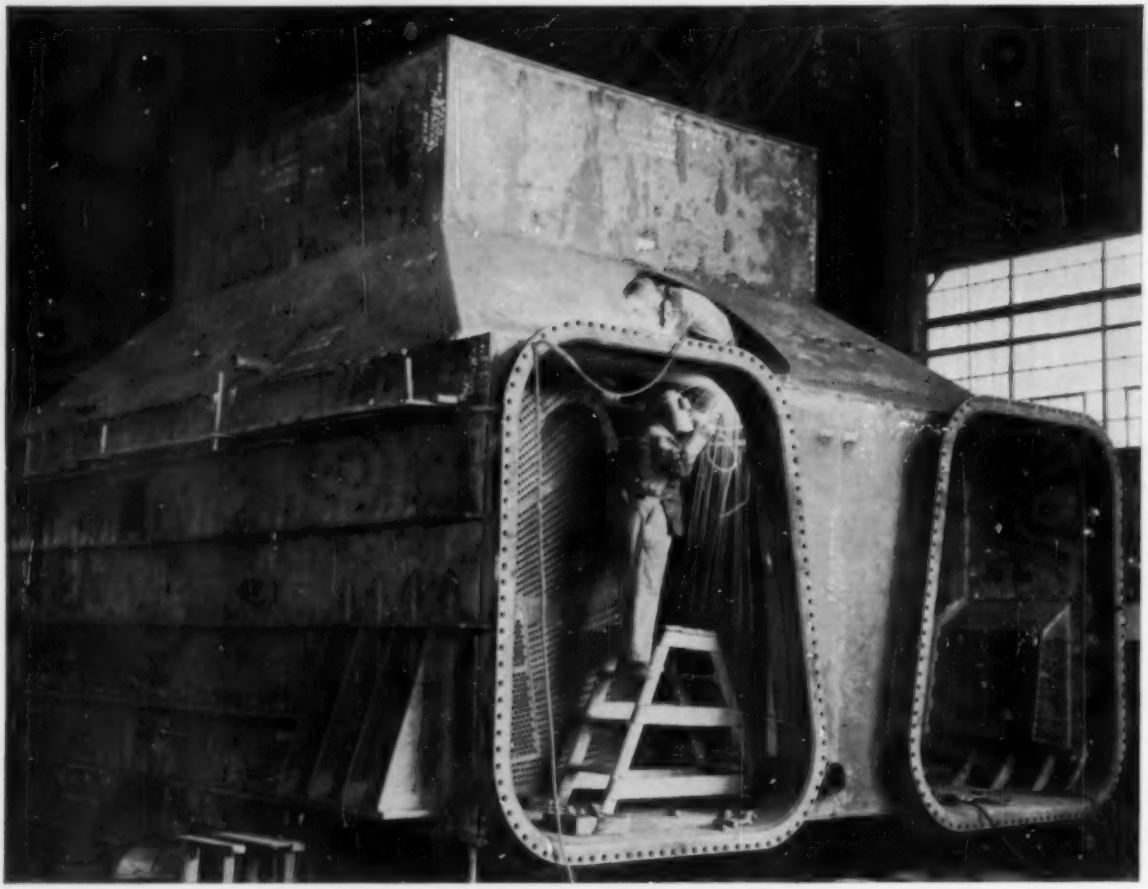

this surface condenser was specially designed to save space

Pictured above in the final stages of construction is a surface condenser designed by Lummus to save much-needed space at the White River Station of the Indianapolis Power & Light Company. The rectangular shape permits low headroom installation. Bayonetting a low pressure stage heater in the dome saves even more space.

This condenser, about to be placed in operation as unit #6 at the White River Station, has a total of 50,000 sq. ft. of tube surface, and was furnished complete with circulating water and condensate pumps and drivers, and a Lummus-designed air ejector unit.

Lummus was highly commended by Gibbs and Hill Inc.—the consulting engineers—and by the customer for efficient handling of engineering details, and for the workmanship which went into the building of the condenser in the Lummus plant. Lummus has been retained to build a second, duplicate unit at Indianapolis' Harding Street Station.

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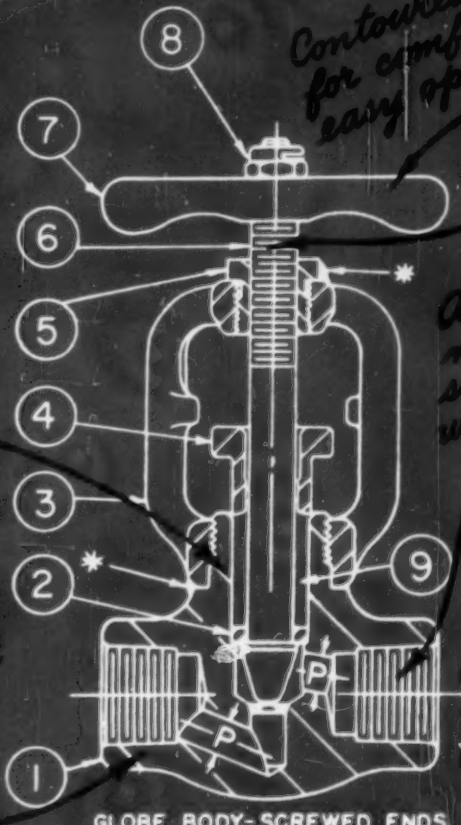

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2	JUNK RING	1	EVALLOY	A.S.T.M. A182 GRADE F6	212
3	YOKE	1	FORGED STEEL	A.S.T.M. A105 GRADE II	111
4	GLAND	1	FORGED STEEL EVALIZED	A.S.T.M. A105 GRADE II	111
5	YOKE BUSHING	1	BRONZE	A.S.T.M. B21	442
6	STEM	1	STAINLESS STEEL 13% CHROMIUM	A.I.S.I. TYPE 416	219
7	T-HANDLE	1	MALLEABLE IRON	A.S.T.M. A47 GRADE 32510	522
8	LOCK NUT	1	STEEL	COMMERCIAL	
9	PACKING		EVALPAK	HIGH TEMPERATURE PACKING	901
10	GLAND BOLT	2	FORGED STEEL EVALIZED	A.I.S.I. C1120	123
11	BOLT WASHER	2	STEEL		
12	BOLT NUT	2	STEEL-EVALIZED	A.S.T.M. A194 CLASS O	124
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Editorial

Trends in Power Plant Engineering

Looking back thirty-five years to information published in engineering magazines in the early 1920's, one discerns many changes in steam power plant practice. At a time of the year when the educational world is holding many graduation ceremonies, it may be advantageous to review some of these changes and to note how they have affected both engineering education and power plant design.

To set the stage, one must realize—or recall—that central stations and industrial power plants shared more in common thirty-five years ago than is true today. For example, the use of multiple boilers on a common steam header system meant that boiler sizes for both utility companies and industrials were very much the same, and this was also true for steam conditions. While stoker firing was almost universally used for burning solid fuel, pulverized coal was just gaining a foothold, with the largest boiler installation at the River Rouge Plant of Ford Motor Company. Most industrial power plants generated steam for power and process, and a large proportion of them operated on an electrically isolated basis.

Much power plant design was of a highly empirical nature, as attested by one of the most popular engineering textbooks of the times, "Steam Power Plant Engineering," by G. F. Gebhardt. Work on chemical treatment of boiler feedwater was in its infancy, and it was extremely unusual for power plant designers to be concerned with metallurgical properties of the materials then in use. Advanced mathematical techniques for stress and fluid flow were practically unheard of, and the developments in modern physics that were to crystallize into the atomic bomb of World War II and the nuclear power plants of today scarcely aroused more than academic curiosity.

By way of contrast, the central station of today is surpassing 400,000 kw in a single boiler-turbine-generator unit, with steam conditions above the critical pressure and at temperatures to 1200 F. Industrial power plants are still being built, but with the exception of the steel, chemical, paper and related industries, electrical power generation is the exception rather than the rule. Only in extremely unusual situations do power capacities exceed 50,000 kw and steam conditions approach 1500 psig, 1000 F. By far the largest proportion of industrial power plants are engaged in supplying process and heating steam at relatively low pressures. With the trend toward standardized design of equipment, the diversity of design in industrial plants has greatly narrowed, and the great amount of engineering pioneering characteristic of the 1920's is not nearly so much in evidence.

Concluding this series of generalizations, it may be written that over the past thirty-five years, central station design engineering has progressed from its earlier empirical base to one in which almost all stages are carried out by teams of specialists in a highly analytical manner. Many of these techniques are also used in industrial power plant design, but the degree of standardization and the generally lower steam conditions result in a level of engineering in which there is more of the routine and less of the trail-blazing atmosphere.

The Pending British Study of River Water Temperatures

"The tight little isle," as Winston Churchill so aptly described his native land, has had to face up, because of its space limitations, to many problems that are as yet only specks on the horizon as far as we in the U.S.A. are concerned. There is one, however—that of determining the allowable heat absorbing abilities of a river stream—of immediate interest to many in this country.

Control over the use of rivers and other waterways as carriers or for fishing has long been vested in some agency of the government, local or national, in both the U.S.A. and Great Britain. The Rivers Act of 1951 (Prevention of Pollution) and its counterpart, the Scottish Act, complicated the scheme of control in Great Britain still further. It granted certain regulatory authority over discharge into rivers and in 1952–1953 difficulties arose with the Yorkshire Ouse River Board in connection with the degree of temperature at which water passed through steam condensers should be returned to the river. A public inquiry was called for on this problem as it applied to the British Electricity Authority's Wakefield "B" power station. The result was an agreed upon interim trial period when detailed observations would be made as to the effect of the discharge of warm water on river conditions. Those observations, we understand, are now underway.

In the meantime there are reports of handicapped cooling system designs planned as a hedge against restrictive future Standards resulting from these observations. Obviously any such handicap imposes artificial limitations on the possible turbine vacuum and hence introduces inefficiencies in the full use of fuels. Any resulting inefficiency in the use of natural resources is the opposite side of the coin that must be considered by those who weigh the effect of temperature rise produced by power plant discharges on river waters. The balance must be struck somewhere between tolerable disturbance to present river use as against a desirably efficient use of natural resources not only of fuel but of the river's cooling powers. The findings and the recommendations of the Ministry conducting this inquiry will be closely studied and we hope that the Ministry will recognize this interest and disseminate the data before reaching any conclusions. Their decision will have far reaching effects in any event and to our way of thinking the broader the sampling of reactions to their findings the better able they will be to pick the proper point of balance.

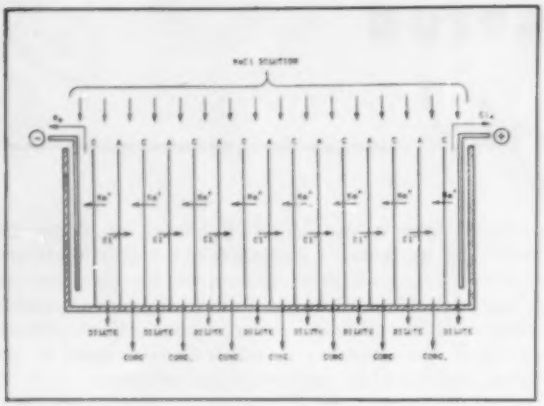

Fig. 1—Fundamental electric membrane water conditioning process alternates anion, cation membranes in series

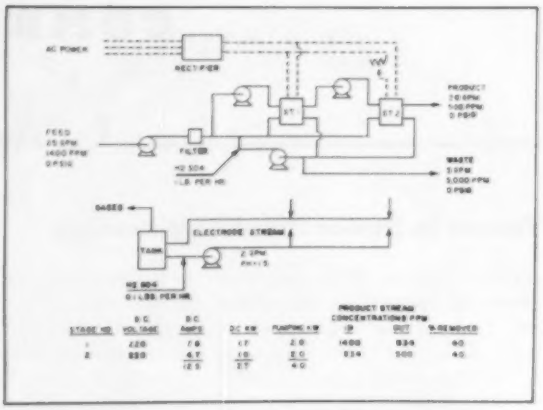

Fig. 2—Utilizing membrane stacks with other auxiliary equipment is shown above for a saline water

*Ion Exchange Membranes for Water Conditioning**

By T. A. KIRKHAM

Director of Engineering, Ionics, Inc.

Ion exchange membranes have been suggested as a means of treating water supplies for many purposes. The author reports a number of smaller plants in operation for the better part of a year. Larger plants are being designed and initial operation of at least one should be obtained this year. Everyone associated with the treating of water should become acquainted with the basic operating principles of this process.

THE world problem of meeting the demand for fresh water is mainly one of distribution. The annual average rainfall throughout the world is approximately twenty times the present average demand for all uses (1).[1] The problem is associated with the fact that the rainfall is far from evenly distributed; in addition, a large fraction evaporates before it can be utilized. Much of the remainder passes into saline sources such as the ocean and underground pools. If it were not for multiple-series use, conditions in many areas might be considerably more serious. Those areas whose natural water supplies are adequate in quantity but are contaminated with dissolved solids are considerably better off than the completely arid areas, but a major development of the area will only result if a process for desalting the water at a cost consistent with the economy of the area is available.

Is the conversion of saline water to fresh water a difficult problem? The answer, of course, is that many processes are available today for accomplishing the conversion and that the problem is basically one of the simplest of chemical separation problems. The major consideration is that the cost of making the separation must be low. The processing of 1000 gallons of sea water to remove 290 lbs of salt or 1000 gallons of a typical brackish water to remove 29 lbs of salt must be accomplished at a total cost of approximately 30 cents if the process is to compare favorably with the average household cost in the United States. Table I shows the range of costs in the United States for industrial, household, and agricultural uses. Indeed, the cost of agricultural water for relatively small production rates on the agricultural scale would barely permit the application of a 3-cent stamp to 4 tons of water. Thus, in examining any process associated with water treating, the major emphasis must be placed on the economics of the process.

Salt Separation Must Be Cheap

All processes for producing fresh water from saline sources can be classified into two groups: (1) those that separate the water from the saline solution; and (2) those that separate the salt from the saline solution. The electric-membrane process is in the latter group. The costs associated with the electric-membrane method, both investment and operating, are strongly a function of the concentration of salts initially present in the feed water. The early interest in this field was not based upon the as-

* Presented before the American Power Conference, Chicago, Ill., sponsored by the Illinois Institute of Technology, March 21–23, 1956.

[1] Numbers in parentheses refer to Bibliography at the end of the article.

TABLE I—ESTIMATED COSTS OF WATER SUPPLIES
(Cents per 1000 gallons)

	50,000 Gallons per Day	500,000 Gallons per Day	5,000,000 Gallons per Day
Agricultural	10	3	0.5–3
Industrial	10–500	2–100	2–8
Household	30–500	30–100	20–60

sumption that the process equipment had to be cheaper than that of other processes, pound for pound, or that the membrane process was bound to be cheaper than others when processing the more saline waters such as sea water. The main theme was that the membrane process can demineralize waters in the brackish range (1000–6000 ppm) more cheaply than other processes could demineralize saline waters of any concentration.

Electric Membrane Process

The operation of the electric membrane process is dependent upon the use of two perm-selective barriers known as cation and anion membranes. The cation membrane is an electrically conductive plastic sheet which permits the passage of only positively charged ions, such as sodium ion, under the influence of a d-c potential. The blockage or repulsion of anions is the result of the fixed negative groups evenly distributed within the insoluble matrix of the cation membrane. The anion membrane is similarly constructed but is selective for anions. A multi-cell system is shown in Fig. 1, each cell being composed of an anion membrane and a cation membrane suitably separated from each other by spacers to permit the passage of the saline water. The membranes are arranged in alternating order with regard to sign and the cells are electrically in series between a single set of electrodes. With the impressing of a d-c voltage across the terminal electrodes, the resulting migration of the ionic constituents results in an increase in salt concentration in one-half the flow passages and a decrease in the others. This basic multicell system can be utilized to separate a multitude of highly ionized constituents from non-ionized or slightly ionized constituents. In the case demonstrated, the ionized constituent is sodium chloride and water is the slightly ionized constituent.

Energy-Capacity Relations

Since the selectivity of the membranes can be shown to be high (>90%), particularly in the brackish water range, the demineralization capacity of the system can be determined using Faraday's Law and remembering that each equivalent of current transfers an equivalent amount of ions through each membrane. The d-c energy input into the system essentially follows Ohms laws, i.e., the power input is proportional to I^2R, where I is the d-c current and R is the resistance of the series arrangement of the cells. A negligible fraction of the energy is associated with the theoretical separation of the salt and water. For a fixed change in concentration of the diluting stream (stream from which salt is being transferred) in passing through the unit, the resistance of the system is approximately constant. The rate of water production or throughput under these conditions is proportional to the current or d-c voltage (Faraday's Law) while the power is proportional to the square of the current. Thus, the throughput of the unit is proportional to the square root of the d-c power input and the d-c energy per thousand gallons produced is proportional to the throughput. In this manner the d-c energy consumption per thousand gallons of water produced for a fixed change in concentration of the diluting stream can be changed over a wide range with a correspondingly radical change in production rate. For example, a membrane system processing sea water on the shore at Cape Cod has been operated at a d-c energy consumption of 10 and 100 kwhr per 1000 gallons on the same day.

For any condition of concentrations and flow rate, there is a maximum d-c voltage or power input that can be tolerated, giving maximum unit production. This limit is the result of a film type concentration gradient being established at the boundary of the membranes. Any further increase in d-c power input would result in decomposition of water, reduced efficiency, and only slight increase in throughput. The higher the velocity of the diluting stream, the greater the permissible power input. Thus, it is not desirable to greatly vary the flow rate of the diluting stream in the operation of a membrane unit.

Unit Resistance

Neglecting electrode overvoltage losses, the resistance of the series of membrane cells shown in Fig. 1 is the sum of the individual resistances of the membranes plus the equal number of flow passages. As an approximation, the resistance of each of the flow passages is proportional to the average concentration of salt solution within the flow passage. The resistances of the membranes, however, are approximately constant, except for Donnan diffusion experienced at the higher concentrations. Thus, for a fixed d-c voltage across the system, at the lower concentrations the system tends to maintain a constant ratio of influent to effluent concentrations of the diluting stream and, at high concentrations, the system tends to maintain a constant difference between influent and effluent concentrations.

The following equation (No. 1) mathematically describes the foregoing energy, throughput, membrane area correlations; since certain assumptions are inherent in its derivation, it should be treated only as an approximate relation. The safe limits of d-c power input and concentrations are indicated.

$$(N_i - N_0)\log_{10}\frac{N_i}{N_0} + 10^{-4}(N_i - N_0)^2 = \frac{6AU}{F} \qquad (70\ F) \qquad (1)$$

where:

N_i = total dissolved solids in feedwater, ppm
N_0 = total dissolved solids in product water, ppm
A = plant membrane-pair area, ft²
U = D-c energy per unit water produced, kwhr per 1000 gallons
F = production rate of product water, 1000 gallons per hour

NOTE:

$$\left(\frac{U}{N_i - N_0}\right)_{\text{maximum}} = 2.5 \times 10^{-2} \text{ kwhr per 100 gallons per ppm}$$

$$(N_i)_{\text{maximum}} = 6000 \text{ ppm}$$

Plant Design

The design of an electric membrane demineralization plant as sold by Ionics, Inc. of Cambridge, Massachusetts, is based upon the utilization of a standard membrane unit known as a membrane stack. The membrane stack is composed of approximately 300 mem-

branes approximately 18 in. × 20 in. × 0.030 in. thick, and separated by the plastic spacers, of approximately the same dimensions, in the manner of Fig. 1. The overall height of the stack is approximately 30 in.; a single set of electrodes serves the stack. The available membrane-pair area for salt transfer is approximately 185 ft^2 per stack. The hydraulic capacity of both the diluting and concentrating streams through the 150 flow passages provided for each is approximately 20 gallons per minute; a pressure loss of approximately 30 psi is required to provide this flow rate, corresponding to an average pumping power per stack of approximately 2 kw.

The method of utilizing the membrane stacks with other auxiliary equipment for dimineralizing saline waters is illustrated in Fig. 2. The typical case chosen for illustration is the production of 28,000 gallons per day of 500 ppm product water from a 1400 ppm brackish water. The total quantity of water required for the product stream (20 gallons per minute) and the blowdown from the waste or concentrating stream (5 gallons per minute) is subjected to some form of pretreatment prior to entering the membrane stacks. The required pretreatment may range from simple sand filtration to aeration, settling, coagulation, chlorination, and sand filtration depending upon conditions. Specific examples are discussed later.

The product or diluting stream is passed successively, by repumping, through the two membrane stacks in series flow. Approximately 40 per cent of the salt is removed in each stack. Thus in two-stage operation, 64 per cent of the salt in the feed water is removed. This corresponds to the maximum safe energy input to the membrane stacks and, for most applications, the maximum energy input in this range of concentrations is the optimum condition from a cost point of view. The d-c voltage to the individual membrane stacks is adjusted by stepped-transformers and rheostats to achieve the proper demineralization. The concentrating stream flows through each membrane stack at a rate of approximately 20 gallons per minute and parallel to the flow of the diluting stream within the stacks. Externally, the concentrate stream flows to the membrane stacks connected for parallel flow within a closed recirculating loop. This scheme permits the utilization of a single concentrate pump and the conservation of waste water.

The recirculating loop is blown down or continuously diluted by introducing raw feed water into the loop. A blowdown rate of 25 per cent or less can be achieved in most cases. In the illustrated case, the total salt transferred is discharged as a concentrated stream of 5000 ppm.

A separate stream, called the electrode stream, serves the electrode compartments at the ends of the stacks. All electrode compartments are connected hydraulically in parallel and a recirculating system is employed. The electrode stream serves two major functions: (1) the removal of dissolved and gaseous products resulting from the chemical reactions at the electrodes, and (2) the prevention of basic precipitates forming in the cathode compartment and adjacent flow cells. The latter is accomplished by continuously feeding a small amount of acid into the recirculating loop. For many waters, it has been found necessary to feed a small quantity of acid into the recirculating concentrate stream to prevent deposition of calcium carbonate. Details are discussed in another section.

By changing the number of stages or stacks in series, waters of greater or less total dissolved solids can be readily handled at maximum power input. Increased production is obtained by adding lines of membrane stacks in parallel with the existing line. For each line added, an increase in production rate of 28,000 gallons per day would be obtained. Because of the polarization phenomenon originally mentioned and the need for maintaining a minimum pressure loss across the flow passages of the membrane stack, it is not desirable to reduce the flow rate per line of membrane stacks below 20 gallons per minute. However, if lower energy consumptions (and greater investment costs) were dictated, stack flow rates as low as 10 gallons per minute could be tolerated.

Economic Considerations

Due to the relationship between plant size, power consumption, and throughput, as expressed by equation 1, it will always be possible to optimize the investment for any particular application. The major costs associated with a thousand gallons of product water can be classified into one of two groups: (1) charges that decrease as plant size is decreased for a fixed throughput rate, and (2) charges that increase as plant size is decreased for a fixed throughput rate. Fixed charges on investment (except rectification equipment), cost of replacement parts, and pumping power fall into group one. D-c power and fixed charges on rectification equipment fall into group two. The minimum total cost per thousand gallons produced occurs, for brackish waters, at the point where the cost of d-c power is approximately equal to the summation of charges of group one. The fixed charges of group one at present-day prices range from 15 to 25 cents per 1000 gallons per stack.

Under these conditions, all plants for processing brackish water, because of power input limitations, must operate at considerably less power than the optimum would dictate. For example, the plant illustrated in Fig. 2 utilizes two membrane stacks, which is equivalent to a fixed charge of 43 cents per thousand gallons for plants in the range of 100,000 gallons per day. The summary on Fig. 1 shows that the energy consumption in the membrane stacks (assuming a 90 per cent rectifier efficiency) is approximately 3 kwhr per 1000 gallons. At 1 cent per kwhr, the plant is far from the optimum power input; however, this is the maximum. If it were possible, the optimum would dictate a plant approximately one-fourth the indicated size and the total cost per thousand gallons would be approximately 25 instead of 46 cents per thousand gallons.

Plant Size—Energy Consumption—Water Costs

The size of membrane plants and the total power consumption required as a function of the total dissolved solids in the feed and product waters are presented in Fig. 3 for the case of maximum power input to the membrane stacks. The correlation of power consumption of Fig. 3 corresponds to approximately 5–7 kwhr per 1000 gallons per 1000 ppm of solids removed. The size of the membrane plant, as determined from Fig. 3, can be directly converted into number of mem-

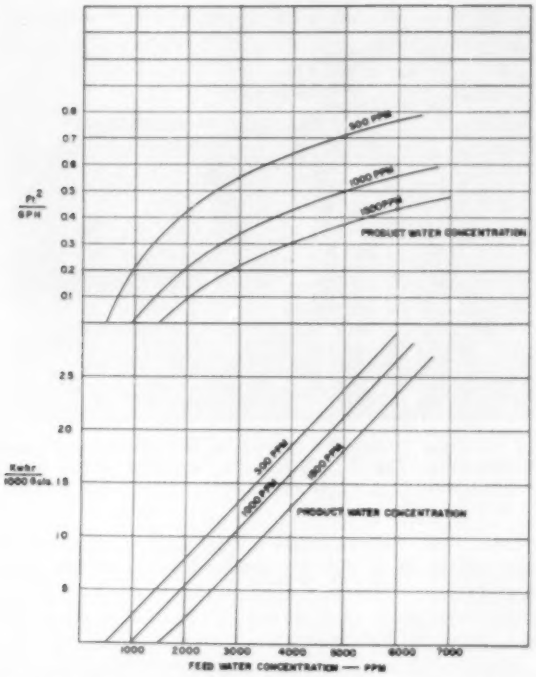

Fig. 3—Size of membrane plants and power consumption required is a function of total dissolved solids in water

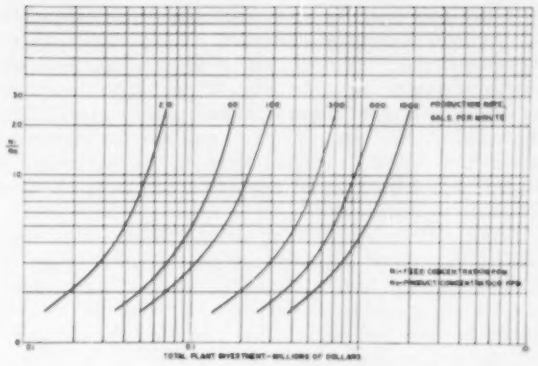

Fig. 4(a)—Investment in dollars for the size of membrane plant selected can be picked off for varying values of water concentrations

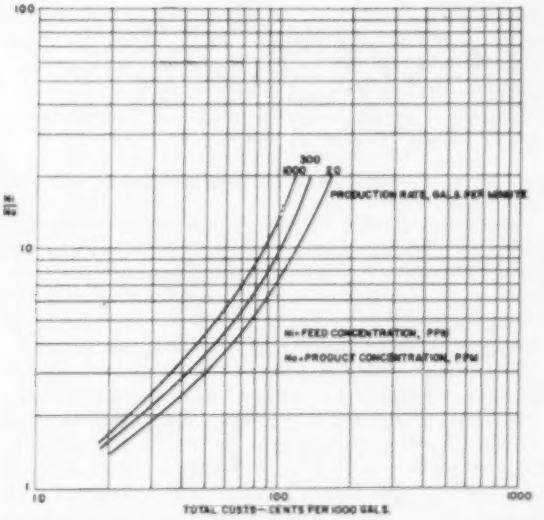
PRODUCTION RATE, GALS PER MINUTE
Ni = FEED CONCENTRATION, PPM
No = PRODUCT CONCENTRATION, PPM
TOTAL COSTS—CENTS PER 1000 GALS.

Fig. 4(b)—Total cost of the water in cents per 1000 gallons for a 500 ppm product water is pictured above

brane stacks. Fig. 4 (*a*) gives the investment in dollars and Fig. 4 (*b*), the total cost of water in cents per 1000 gallons for the case of maximum power input and minimum investment. The investment plot can be directly utilized for any values of feed and product water concentrations; Fig. 4 (*b*) was prepared for the case of 500 ppm product water but can be used for any value of product water concentrations, realizing that the costs will be high by a maximum of 20 per cent. The assumptions made in preparing Fig. 4 (*a*) and 4 (*b*) are as follows:

1. Investment amortized over 25 years at 3 per cent interest.
2. Yearly replacement of anodes.
3. Replacement of membranes at the rate of 33⅓ per cent per year.
4. Cost of maintenance materials at 2 per cent per year on non-stack components.
5. One hundred man hours per stack per year for operating and maintenance labor.
6. Energy at 1 cent per kwhr.

The investment figures include materials, direct labor, building, auxiliary services, engineering, and construction supervision. Excluding the energy to the rectifier and stacks, the approximate breakdown of cost per 1000 gallons of water is as follows:

	Per Cent	Cents per 1000 Gallons per Stack
Membrane replacement	42 to 46	5.5 to 10.0
Investment amortization	23 to 28	3.6 to 6.1
Operating and maintenance labor	9 to 13	2.0
Replacement parts	9 to 10	1.5 to 1.9
Pumping power	8 to 11	1.7
Acid	1 to 4	0.2 to 0.4

Membrane replacement is by far the greatest single cost factor. The replacement rate of one-third per year is a conservative estimate based upon the first year of operation of several plants, including the experimental plants. Lower membrane manufacturing costs and lower membrane replacement rates can be expected to significantly reduce the operating costs of membrane plants. Simultaneously, a lowering of fixed charges on investment will result, but to a lesser degree since membranes constitute only about one-third of the total investment costs.

The foregoing cost information is the result of estimates made by Ionics, Inc., based upon information accumulated during the design, construction, and operation of the several membrane plants in existence today. Allowances have been made on a reasonable basis to cover all significant costs.

The total costs presented in Fig. 4 (*b*) vary from a low of approximately 20 cents per 1000 gallons for a 40 per cent single-stage operation in a plant of 1,400,000 gal-

lons per day to a high of $1.33 per 1000 gallons for 92 per cent five-stage operation in a plant of 28,000 gallons per day. Of these total costs, the energy to the stacks accounts for only 3 to 25 per cent depending on the number of stages. It was determined in 1954 that $125/AF (38¢ per 1000 gallons) for municipal waters and $40/AF (12¢ per 1000 gallons) for irrigation waters represented about the maximum costs of water for these two uses (2).

Some definite conclusions can be drawn from these present-day costs. Except for special crops of an extremely valuable nature, the use of the electric membrane process for agricultural purposes today is not feasible. However, for household uses, the electric membrane process can demineralize saline waters for total costs approximately equal to or less than the costs being incurred today in many parts of the world and the United States. The average family in the United States today spends approximately $20 per year for water. At $1.00 per 1000 gallons, this yearly cost would be increased to about $60, which would not be a significant factor to the average family. The demand for household water would not be materially affected by such a price and the development of new water sources and the expansion of existing water supplies can be expected to be able to bear such an additional cost.

Review of Field Operations

There are in operation as of February 1, 1956, eight Ionics electric membrane plants, demineralizing saline waters for various purposes. In addition, a considerable number of new plants will be installed and will start producing in 1956. Table II is a summary of the statistical information concerning the operation of the plants.

Plant No. 1, which was the first successful installation, operated essentially unattended and was instrumented to shut down and sound a warning if an abnormal condition developed. This type of automatic operation is a required feature of all Ionics membrane plants in operation today. The plant located on the shore at Cape Cod required a start up and servicing call approximately every 2–3 weeks; operation was discontinued in the spring of 1955 because of the experimental nature of the plant.

Plant No. 2 produces drinking water for a mining camp consisting of 150–200 men. Operation of the unit, for the most part, has been unattended.

Plant No. 3 is a mobile unit supplying fresh water for an exploration crew of approximately 30 men. The brackish water is obtained from a number of deep wells whose solids content varies considerably. In addition, large quantities of H_2S and dissolved and suspended iron have been encountered. To obtain more efficient operation, the plant has been recently located at one of the more desirable well heads.

Fig. 5—First so-called continuous ion-membrane plant at the Texas Electric Service Co. employs a four-stage installation

Plant No. 4 is the first so-called continuous plant designed, built, and operated. Due to the fine cooperation rendered by the Texas Electric Service Company, this plant was instrumental in supplying basic design information and contributing to the solution of the several common problems that arose. Fig. 5 is a picture of this four-stage plant.

Plant No. 5 is a mobile unit operated for a period of about 10 months under the joint direction of Ionics, Inc., and Department of Interior. Two sites were chosen for the experimental work as indicated in Table II. The direct labor requirement for maintenance and operation of 100 man-hours per stack per year utilized in cost calculations was obtained as a result of testing this plant. Some of the major contributions made to improving the electric membrane process were the result of the Department of Interior tests.

Plant No. 6 was designed and constructed very rapidly; it is the most modern of the plants operating today. The improvements made possible by the operation of the experimental plants were incorporated into its design. It is the first continuous type commercial plant and has achieved a remarkable record of more

TABLE II—SUMMARY OF FIELD INFORMATION[1]

Plant No.	Operating Organization and Location	Date of Start-Up	Type of Plant[2]	Purpose of Plant[3]	Source of Water	Total Hours Operation	TDS, ppm. — Feed	TDS, ppm. — Product	Production Rate, GPH	D-C Power Demand	Plant Membrane Pair Area, Ft²	Total Energy Consumption, K whr/1000 gal.
1	Ionics, Inc., Eastern Seaboard	2/54	B	X	Ocean	5300	32,000	300	17	0.9	100	100
2	A[4]	6/54	B	P	Well	6900	2,400	1000	100	0.4	75	20
3	B[4]	10/54	B	P	Well	3000	2,000	500	200	0.4	125	15
4	Texas Elect. Service Co., Wichita Falls, Texas	10/54	C	X	....	4500	1,700	400	1200	4.5	500	12
5	Department of Interior Buckeye, Arizona	1/55	C	X	Well	740	4,000	400	1000	9.2	750	20
	Miller, South Dakota	8/55	..	..	Well	540	2,000	700	1700	5.7	....	10
6	Bahrain Petroleum Co., Bahrain	6/55	C	P	Well	5000	3,150	400	1260	8.4	937	16
7	Bureau of Yards & Docks, California	9/55	B	X	....	1500	3,500	175	75	0.8	106	15
8	U. S. Air Force, Texas Tower #2	11/55	B	P	Ocean	1000	32,000	500	60	6.4	375	150

[1] All figures are averages. [2] B—batch; C—continuous.
[3] X—experimental; P—commercial production. [4] Customers prefer non-disclosure.

than 90 per cent on stream time during the first seven months. The output of approximately 30,000 gallons per day supplies approximately 60 per cent of the fresh water demand for a small town of several thousand people in a hot, arid section of the Middle East. Operation has been so satisfactory that the plant is in the process of being expanded to three times the present capacity. Initial operation of the expanded plant is scheduled for June, 1956.

Plant No. 7 is the first of two pilot plants under evaluation by the Bureau of Yards and Docks laboratories in California. Tests are presently in progress.

Plant No. 8 is located on the first of the Texas Towers to be located along the northern eastern seaboard as offshore radar stations. This is the first commercial sea water unit and supplies part of the fresh water requirement for the 60 odd men manning the station.

During the operation of the foregoing plants over the last two years, many important facts and solutions to problems were uncovered, a few we mention in detail.

Solids Removal

Because of the fine passages provided for flow within the membrane stack, it is necessary to remove any significant amount of suspended solids from the feed water. Most suspended material of organic nature tends to adhere to the surfaces of the membranes, forming a slime. Deep well waters in general require no filtration; on occasion, silt or sand is entrained due to the pumping action and rapid-sand filtration or settling is required.

For most surface waters where colloidal material is found in suspension, coagulation and sand filtration is required. If the concentration of material is low (<20 ppm), diatomite earth filtration is satisfactory.

Bacterial Growth

It was generally found that the membrane stacks serve as a breeding ground for many types of bacteria found in non-sterile water. No significant attempt has been made to isolate the types of bacteria that were involved. If the feedwater and membrane system are initially free from bacteria, no build-up occurs. Large multiplications will occur in the membrane stack if bacteria are present in the feedwater. Prechlorination to maintain a residual in the product water has solved the problem.

Iron Fouling

Waters containing 0.3 ppm of iron or less have been successfully treated for thousands of hours without pretreatment. Waters containing 1.0 ppm of iron or more deposit a brown slime on the surfaces of the membranes which may eventually affect the performance of the system. The removal of the iron by oxidation (aeration or direct chlorination) and filtration is recommended if the iron concentration is 1.0 ppm. or so.

Iron-Hydrogen Sulfide Fouling

In the Middle-East area, waters containing large amounts of iron (5 ppm) and hydrogen sulfide (60 ppm) were encountered. Much of the material was in the form of suspended iron sulfide; the untreated water deposited an adherent black glossy film on the surface of the membranes which could be removed only by chemical treatment. Many membranes became brittle and ruptured under these conditions. It was necessary to remove this material from the feed water which was accomplished by direct chlorination followed by filtration. A large installation would employ aeration-settling to reduce the chlorination-filtration load.

Scaling

The majority of brackish waters encountered are supersaturated in calcium carbonate and many are close to being saturated in calcium sulfate. Since no significant heating of the water is involved during the demineralization process, one might expect that no deposition of scale would result. Operation on brackish waters has shown that no scaling normally occurs on the membrane surfaces bounding the diluting stream; however, calcium carbonate scale does form on the side of the anion membrane facing the concentrating stream. No scaling of the cation membrane has been experienced. The scaling of the anion membrane appears to be a pH controlled phenomenon which seems to be almost independent of the blowdown rate.

The solution to the calcium carbonate scaling problem has been relatively simply accomplished by the continuous feeding of sulfuric acid to the blowdown stream to reduce the concentration of bicarbonate ions. No change in pH of the diluting stream occurs, and a pH change of about 0.5 units occurs on the concentrating stream. Approximately one pound of concentrated sulfuric acid per thousand gallons of demineralized water is the average acid consumption. Costwise, this amounts to 1 to 2 cents per thousand gallons, which is a negligible cost factor. Not only does the addition of acid in this manner prevent scaling, but also effectively removes scale from plants even after weeks of accumulation.

Calcium sulfate scaling has been less serious and can be completely controlled by providing adequate blowdown. It has been found possible to continuously operate with a blowdown stream approximately 20 per cent supersaturated in calcium sulfate. When calcium sulfate precipitation does occur, it forms as a non-adherent material within the flow passages of the concentrating stream which is easily removed by flushing.

The Future

It is difficult to project very far into the future. Through the mediums of improved design such as the perfection of a large basic membrane stack, simplification of equipment, utilization of cheaper materials of construction, and mass production of stacks, lowering of costs will result. And with the lowering of cost, greater areas of utilization of the equipment will open up. However, it cannot be expected that most of the improvement will take place until a significant number of plants are constructed under the present design methods, using present equipment. In the final analysis, the major improvements can only be obtained as the industry itself grows. The needs of the world for cheap demineralized water practically guarantee that this will take place; estimating the growth-time curve is the difficult task today.

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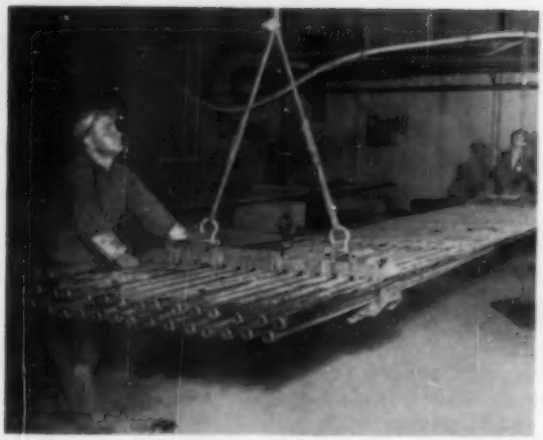

Fig. 1—A solidly tied together panel of boiler tubes such as above benefit from a reduced likelihood of individual tube damage in shop handling for shipment

Fig. 1A—Railroad cars can be unloaded faster with mechanical assistance and tube panels can be neatly stacked by the same means

The Cromby Story—Case History in Panel Construction

By W. C. NORRIS* and WALTER RUPINSKI†

Combustion Engineering, Inc.

Shop assembly by panels, 4- to 12-ft wide, 40- to 60-ft long, of 1½-in. or 3-in. boiler tubes tangent to one another has produced definite savings in quality control of the end product as well as improved shipping and field handling and storage at the erection site. The accompanying pair of articles presents first the manufacturer's viewpoint for background and for the second part the first field experience of a prominent utility.

FOR many years pressure parts for large power boilers had been designed, fabricated and shipped in complete "knocked down" form and comprised literally hundreds of separate pieces. Each separate piece required individual inspection, handling and preparation for shipment to the field. Further, each piece was given a separate identification marking or piece number.

Field erection techniques were consequently directly influenced and, in fact, dictated to a large extent by these same design and shop fabrication methods. Each of the "hundreds of pieces" upon receipt in the field had to be unloaded and accounted for, identified by piece number and carefully stored for ready access when required for erection. Next, each individual piece had to be handled again from storage for reloading and moving to the boiler house for erection. Lastly each of the many component parts had to be individually erected, properly aligned in their respective positions and welded or mechanically secured in permanent position.

In January of 1952 the installation of Combustion Engineering, Inc.'s first controlled-circulation unit was commenced for Virginia Electric & Power Company at their Chesterfield Station, Dutch Gap, Va. Within a few weeks several members of C-E (and particularly those of its Erection Department) realized that certain sections of the steam generating equipment being erected by the long established but outmoded methods would lend themselves readily to new erection techniques—specifically the small-diameter waterwall tubes featured in controlled circulation designs. These small tubes measure about 40 ft long but only weigh approximately 80 lb each. Yet at the time of the Chesterfield Station installation they were being handled individually through their entire erection sequences, i.e., unloading, identifying, storing, moving to the boiler house, cleaning ends, sounding (checking against possible internal obstructions), raising to position, aligning and welding to position, by identically the same methods and at the same manpower expenditures as those employed in the complete handling and erection of large diameter tubes weighing four times as much.

These established erection methods were, of course, of the "time-tested and proven" variety being typical of those generally practiced in boiler erection by all boiler manufacturers. However, it was quite obvious, especially for the lighter weight tubes, that these methods

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were unduly expensive, impractical and, in reality, obsolete. Further it was quite evident that something could be done immediately to rectify this unsatisfactory erection procedure.

Shop Assembly of Panels

The immediate result was the development and use of a multiple lifting jig to handle six to eight tubes simultaneously and with approximately the same man-hours previously expanded in the complete lifting of a single tube. Out of this attempt to combine a number of tubes into a single assembly came the idea of having the boiler shops furnish furnace tangent tubes in panels of suitable dimensions for shipping and practical field erection.

The benefits to be expected from a program of shop paneling of tubes were fully analyzed from the standpoint of both shop and field experience. The immediate shop advantages seemed to be:

(1) An improved quality control of the end product. The panel assembly jig is the focal point of all shop operations in the tube bay. After the individual tubes have the various offsets pressed out, they are set up on an assembly jig which, in essence, simulates an as-erected condition in the field for a given panel. The inspector can then carefully check out a large section of a given furnace at one time for overall dimensions, and at the same time, location of door openings, if present, or instrument inserts. The possibility of error from the human element is lessened further by the fact that inspections are carried out on a hundred or so panels for a complete installation as against several thousand individual tubes.

(2) A facilitated shop loading program. All shipping supports such as strongbacks are tied to the tube panel assembly while still in the assembly jig. The Shipping Department need handle only a panel measuring from 4- to 12-ft wide and 40- to 60-ft long instead of a series of individual tubes of $1^1/_2$ in. O.D. and 40- to 60-ft long. In addition the Shipping Department benefits from large, easily seen, panel-identifying marks so that it takes less time to clear a shipment of boiler parts into the railroad cars.

(3) A decreased shop storage space for panel work. The compact panel assemblies not only facilitate loading of railroad cars but permit neat, economical use of space in shop storage areas as well. The solidly tied together tube panels reduce tube damage in handling through the shop to the shipping bay.

In summation, panel work in the shop improves the quality of the product fabricated, makes control through the various fabricating functions easier, more efficient and less costly.

The field benefits from shop paneling were expected to develop in the handling of shipments into and out of field storage, in reduced storage requirements, in savings from decreased shipment damages and field corrections of shop errors and in faster closing of furnaces. The advantages would occur in these areas, it was felt, for the following reasons:

Shipment Handling. (1) A faster, more economical unloading of railroad car shipments, Fig. 1A.

(2) An elimination of the usual tube assorting since all tubes are accounted for in panel fabrication, Fig. 2.

Fig. 2—On-the-site storage of boiler panels can be planned to meet a systematic erection schedule by storing according to identification markings

(3) A reduction in handling time from storage space to final position in the boiler assembly because of more compact storage and easier identification of desired parts.

Better Equipment Conditions. (1) A freedom from accidental bending of individual tubes in shipment since panels can be uniformly piled and supported in the railroad cars.

(2) An elimination of dissimilar tube lengths which result in field corrections requiring cutting, grinding and scarfing operation of the tubes.

Furnace Closing. (1) A shorter elapsed time in closing in furnaces. The use of panels 4 ft by 40 ft should permit a definite reduction in the time to assemble furnace walls.

Solving Anticipated Problems

The limited access to field welded joints dictated by tangent tube design was immediately recognized and a study was made to minimize and, if possible, completely eliminate this access problem. With the collaborative efforts of our Shop, Erection, Engineering, and Production Departments several test panels comprised of 32 $1^1/_2$ in. O.D. × 0.165 in. thick wall tubes on $1^{33}/_{64}$ in. centers (or $^1/_{64}$ in. spaces) were set up in our Chattanooga shop to simulate some of the possible shop problems in fabrication and handling, as well as those anticipated with field erection. A tube raising, supporting, aligning and spreader jig comprised of channels, pusher bars and other structural members was developed to circumvent the tube panel weld joint access problem.

These jigs permitted raising the panel as a unit and at the same time uniformly spreading the tube ends sufficiently for accessibility in performing the welding by the heli-arc, metal-arc or oxy-acetylene processes. Here is how these jigs have worked out.

When the tube welds have been completed and the jigs removed, the tubes then return to their original vertical plane and re-assume the tangent relationship with one another. These jigs incorporate three other features necessary to economical tube panel erection. These being provisions for the raising, supporting and aligning of all tubes simultaneously, until the joints are

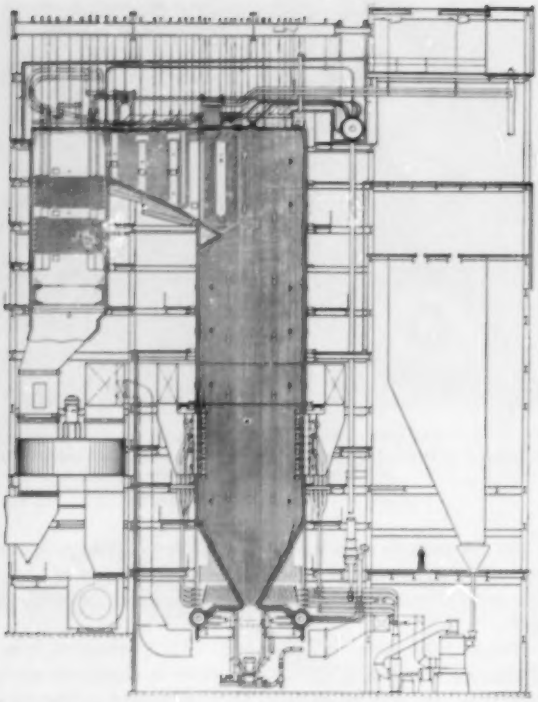

Fig. 3—Cross-sectional view of the Cromby No. 2 unit, a 1,450,000 lb per hr twin furnace design delivering steam at 2075 psi, 1000 F, and 1000 F reheat

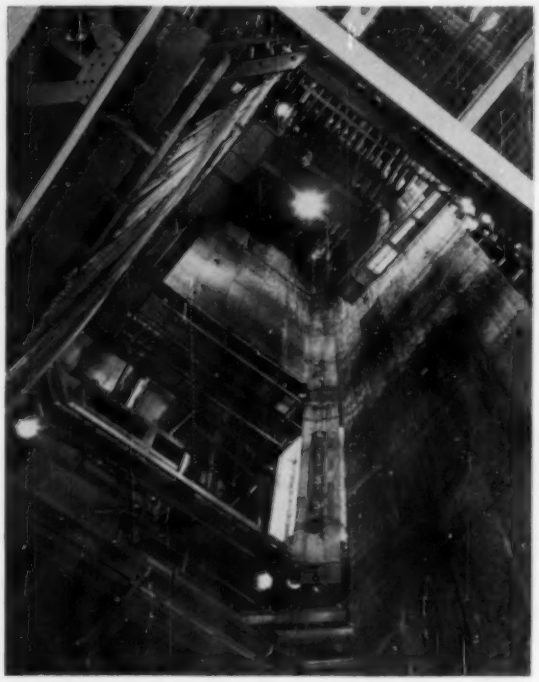

Fig. 4—Erection view of the No. 2 unit shows a corner burner panel assembly being raised into place for necessary welding operations for final positioning

completely welded. All field experience to date indicates this device has proved completely successful.

Development work confirmed by actual rigid shop tests demonstrate that tube panels will withstand all normal shipping and field handling operations and remain intact by the installation of relatively short fillet welds between all tubes. Also, it has been shown that three or four strongbacks firmly secured by strap iron bands provide ample support for the panels in shop handling, shipping and field erection.

In addition another advantage the tube panel assembly permits is a single tube-end protection plate designed to replace the 32 to 35 individual caps heretofore used to protect each separate tube-end during shipment and storage prior to erection.

The First Installation

With all forseeable shop and field problems believed solved, a decision was reached to select the first field installation which would employ these tangent tube panels. The unit decided upon was that for the Cromby Station of the Philadelphia Electric Company. This was a twin-furnace controlled circulation unit rated at 1,450,000 lb per hr, 2075 psi, 1000 F total temperature with 1000 F at the reheater outlet, Fig. 3. The two side walls, the front wall and the rear wall up to but not including the deflection arch were to be arranged in panels with the exception of the lower terminal ends connecting to the water wall drums. All the field benefits with tube panels enumerated above were fully realized in this first installation and the expected economies were more than fulfilled.

These include complete headers and header sections shop-attached to the tubes where design permits, as well as partial skin casing bars, channels and other tube attachments where tube flexibility is not interfered with. Panel sizes have been increased appreciably both in width and length but are still confined to dimensions which lend themselves to shipping limitations, and practical field erection applications.

The paneling program has been expanded to include natural circulation units with large diameter tube panels as well as controlled circulation units with small diameter tube panels. Many of these units have been erected and in service with many more in fabrication.

Out of this experience a number of other possibilities for economies in time, labor, space and work scheduling became evident. The receipt of compact, sizable boiler wall units rather than a host of individual pieces suggested a problem in logistics reaching back to shop work scheduling and carrying through to specific stages in the field erection. Field erection of the unit as well as the shop experience with the tube panels indicated that the surface had been barely scratched and Combustion Engineering have since expanded this new technique to other areas of their boiler units, i.e., the steam cooled walls, the economizer extended walls, the extended side walls, and also the rear wall deflection arch surfaces.

Editor's Note:

The above article is a brief account of the manufacturer's viewpoint of this construction method. The facing page relates a purchaser's experience.

Field Experience on The No. 2. Boiler—Cromby Generating Station

By E. F. SHEEHAN*

Philadelphia Electric Company

IN THE erection of the second of two steam generators at the Philadelphia Electric Company's new Cromby Station, Combustion Engineering, Inc., employed a method of furnace wall erection new to our experience; namely, the handling of wall tubes in panels that had been assembled in the boiler shop.

The steam generator, Fig. 3, at the new Cromby Station of Philadelphia Electric Co., consisted of two furnaces, each approximately 25 ft square inside by 110 ft high. At the upper rear of each furnace was a rear pass. These two passes became a common section housing the primary superheater and economizer. The secondary superheater (pendant elements) was suspended in the upper rear and rear pass of one furnace, and the reheater was suspended likewise in the other furnace. The pendant elements of the superheater and reheater, and the elements of the economizer were delivered in sections or panels for erection, which method has been used by other erectors for our generating station construction in the past. However, on this particular job, the Combustion Engineering Company also shipped the furnace wall and roof tubes in panels. It is this innovation which prompts this article.

Each of the two furnaces was handled in the same manner. Panel construction was used for the front and rear tubes from the roof header in the center of the roof through the throat at the furnace back to the lower headers, Fig. 4. On the front wall, this was broken up into the roof section panels, vertical wall panels and furnace bottom panels. The rear wall was treated similarly except for the area of the rear pass. Both side walls were constructed of vertical panel sections from top header to the bottom connection at the lower headers. All four corners of each furnace were 45-deg chamfers, and tubes were paneled for the corners. All wall openings for soot blowers, furnace doors, burners, tie bars, etc., were incorporated in the made-up panels.

The Erection by Phases

Starting with the delivery of panels in railroad cars to the job site, many advantages of this panel type fabrication were experienced. The unloading from the car to yard storage was simplified. The tube panels were in widths of approximately 3 to 5 ft, clamped with wood yokes. With the basic wall tube size of 1 $^1/_2$ in. outside diameter, anywhere from 24 to 40 tubes were assembled in each panel. Each panel was labeled for identification in erection. The unloading and stacking of these panels, and also arranging for future pickup to move into the erection area for proper sequence was much simplified over handling single tubes, with consequent savings of time and cost. Furthermore, the panels were much less subject to damage in handling and stacking with reduction in tube repairs. Another advantage was recognized in that tube-end protection covers were less likely to be disturbed with neater storage piles. Again, neater storage required less storage space, Fig. 5.

On movement of the tube panels from storage for erection, the pickup at the storage site and unloading in the basement under the furnace area was simplified. Handling time and costs were reduced. Another advantage to the general contractor was that material handling by the Combustion Engineering Company erector interfered less with other crafts and contractors.

In preparing the panels for installation, each tube was air blown to check for possible obstruction. This operation was reduced in time over single tube work by the convenience of blowing each tube across the panel in succession in approximate position with the wood yokes still in place. A jig was fastened to the tube panel which spread the tubes for welding and tubes were welded to member above. As installation and welding progressed, the next panel sections were hung on the next above sections and again spread for welding with the jig. After the tubes were installed and welded throughout, the walls were planed against the buckstays, and welded in place. Except for the above mentioned jig, no special handling other than normal rigging was required.

From the customer's viewpoint, the panel method of tube erection was successful on this first experience in view of the reduction in erection as well as the simplification in storage and handling problems noted above. No doubt more study and improvement will be made to realize more fully the advantages of this type of construction. We appreciate and encourage such efforts.

Fig. 5—Neat storage piles of tube panels permit the maximum use of allotted storage space and require less area

* General Superintendent of Construction.

This is a conference about a new plant . . .

which man is the president of the company?

The man on his feet is *not* the president of the company. He's the chief engineer.

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CARRIER OF FUEL SATISFACTION

The Place of the Gas Turbine in Electric Power Generation*

By A. O. WHITE†

General Electric Co.

Major boiler companies as well as the gas turbine builders have been studying the application of the gas turbine in a supercharged boiler cycle to central station or large industrial plant power generation. Here is an excellent report on the present status of the gas turbine in this activiy and enough background to explain the optimism many hold for this device.

THERE were in service in the world, as of March 1, 1956, gas turbines with a total rating of approximately 1,500,000 kw. Of all known units, 101 are for power generation and 123 for other applications such as compressor and pump drives for industrial use. In the U.S.A. there are 107 gas turbines in use, of which 21 are for power generation, and 86 for various industrial applications including 53 for gas pipeline pumping.

In addition, there were ordered during 1955, so far as we know, 77 gas turbines here and abroad, of which 27 were for power generation. Of the total, 23 units were ordered from foreign manufacturers and 54 from domestic builders. Thus, there is ample evidence of the acceptance of gas turbines throughout the world, and in the power generation field.

Gas turbines have been built with ratings from about 40 hp to 27,000 kw, and have been applied to a wide range of uses; from small emergency pumping sets, pipeline pumping units, chemical plants and steel mill applications through transportation applications including automobiles, airplanes, locomotives and ships to the large central station power generating units. Cycles used have ranged from the simplest open-cycle, single-shaft units, to the complicated high-efficiency cycles incorporating intercooling, reheat, regeneration, etc., with multiple shafts in both closed and open cycles. The cycles chosen for each particular application are governed by the economics of the situation and the predilections and experience of the purchaser and manufacturer.

The gas turbine has certain inherent characteristics that can be taken advantage of in most applications. It is a form of internal combustion engine, and as such, can be made as a complete, self-contained, prime-mover. Its requirements for cooling, particularly cooling water, can be made very low, by the choice of an appropriate cycle. It requires a minimum of floor area and building volume for a given rating, and its thermal efficiency can be made competitive with other engines if the extra complication and cost are warranted by the expected fuel costs and load factor. Finally, it can burn a wide range of fuels, including low-cost specification residual fuels. Its chief disadvantages are its present inability to successfully burn coal or other solid fuels, and a current limitation in size to about 30,000 kw in a single unit.

The operating experience with gas turbines has, in general, been very satisfactory. Their availability and reliability have, in most cases, been very good. There are a number of units in service that have availabilities equal to those of a modern central station steam plant and maintenance costs are equally favorable. Its position as a prime-mover suitable for central station application, is well established.

Of the 101 units for power generation presently installed in the world, 21 are in the United States and these are probably of most interest. Table I lists these units and their chief characteristics. These installations fall roughly into two classes. The first, historically, is the installation of a gas turbine in an existing steam plant. In this application, the prime purpose is to get more station output. By using the heat in the exhaust of the gas turbine to do feedwater heating, the steam turbine output is increased and the overall station heat consumption improved. The best known of these applications is the one at the Oklahoma Gas and Electric Company's Belle Isle Station, which has been fully described in the literature (1).[1]

The other application is as back-up for a hydro system or transmission line, or for peak load service. Such units are those installed on the systems of Central Vermont Public Service Company, Bangor Hydro-Electric Company, Connecticut Light and Power Company. As can be seen from the table, these units cover a range of types; from the simple-cycle, single-shaft units installed at Belle Isle to the intercooled regenerative two-shaft units installed on the Connecticut Light and Power System.

Most of these units have given a very good account of themselves. The units at Oklahoma Gas and Electric in particular have accumulated, as of March 1, 1956, 36,473 hours on No. 1 and 16,452 hours on No. 2 units. All this points up the importance of the gas turbine in the power generation field, and the industry is confident it will take an ever-more important place as time goes on. It does not, of course, have universal application; but it can be a valuable addition to the country's power

* Abstracted from a paper of the same title presented before the First Annual Power Symposium, Philadelphia Section, American Society of Mechanical Engineers, April 24, 1956.

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[1] Numbers in parentheses refer to the Bibliography at the end of the article.

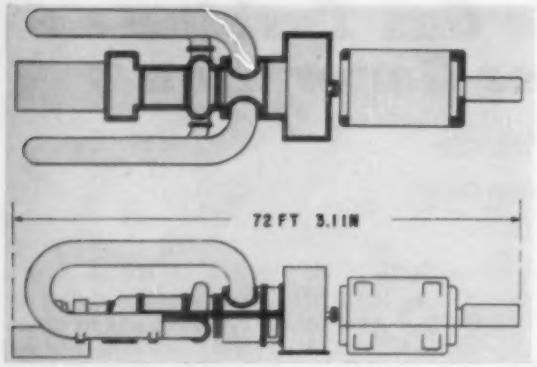

Fig. 1—Water injection, single-shaft gas turbine, 23,000-kw peak capacity

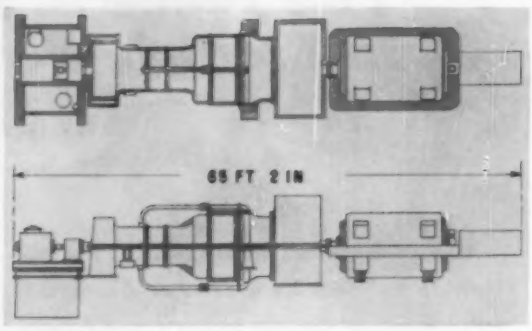

Fig. 2—16,500-kw simple-cycle, single-shaft gas turbine-generator unit

systems when properly applied. The rest of this paper will be devoted to a description and analysis of such applications.

Where fuel costs are high (30¢/10^6 Btu and up) or the load factor is high, the thermal efficiency of a plant is of importance. In its simplest form, the gas turbine provides a low-cost moderate efficiency plant; but the addition of a simple regenerator improves the efficiency about 30 per cent at a relatively low cost. In the larger sizes, a regenerative cycle gas turbine will have efficiencies and corresponding heat rates approaching those of a comparable size steam plant. Thus, they are suitable for use in a central station power generation plant wherever space is at a premium, cooling water is scarce, or operating personnel are scarce, expensive, or relatively unskilled. Also, a gas turbine plant will install, in general, for somewhat less per kilowatt than a comparable steam plant, and so is economically attractive unless the load factor is quite high.

We have made studies of the installed cost of gas turbine plants, and the results are presented in Table II to give an order of magnitude figure. It must be realized that these figures are based on neither an actual installation nor detailed cost estimates, but are carefully prepared figures based on typical plant layouts that we feel give a relative picture of gas turbine plant costs.

As for thermal efficiency and corresponding heat rates, a comparison of gas turbine plants with modern steam plants of the same rating is made in Table III. Diesels or gas engines may be considered competitive in some cases; but their higher maintenance and lube oil costs renders them less economical in most cases, even where fuel costs are high and their better efficiency would otherwise pay off.

Choosing Application

In surveying the possible field of application for gas turbines, their use for standby or peak-load service appears immediately as an attractive possibility. Here, the inherent characteristics of the gas turbine, i.e., low cost per kilowatt, quick starting, very low water requirements, ability to burn a wide variety of fuels, and ability to be operated as a remote, unattended station, uniquely fits it for such service. Most of the electric power generating gas turbines installed, or on order in the world today, are for just such service.

A complete discussion of the economics of peak-

TABLE I—DOMESTIC UTILITIES USING GAS TURBINE GENERATOR SETS AS OF MARCH 31, 1956

Utility & Location	No. Units	In Service	Cycle*	Kw-Rating	Fuel	Application
Oklahoma Gas & Elec. Huey Station, Belle Isle (near Okla. City)	1-GE	7/29/49	SC-1S	3500	Nat. gas	Base load; heat balance; exhaust preheats feedwater
	1-GE	7/21/52	SC-1S	4000	Nat. gas	
Central Maine Power Co. Farmingdale, Me.	1-GE	8/30/50	SC-1S	3500	Distillate	Peak load and standby
Bangor Hydro-Electric E. M. Graham Station. Veazie, Me. (near Bangor)	1-GE	10/28/50	RIC-2S	5000	Specification Residual oil	Peak load and standby; hydro supplement
	1-GE	3/7/52	RIC-2S	5000		
Public Service of Okla. Elk City, Okla.	1-GE	6/16/51	RIC-2S	5000	Nat. gas	End of line; peak load
Central Vermont Pub. Serv. Rutland, Vt.	1-GE	8/27/51	RIC-2S	5000	Specification	Peak load and standby; hydro supplement
	1-GE	6/4/52		5000	Oil	
	1-GE	5/10/53		5000		
Texas Power & Light Co. Gainesville, Tex.	1-GE	4/25/52	RC-2S	4000	Nat. gas	End of line; standby and peak load
West Texas Utilities Co. Stockton, Tex.	1-W	1952	SC-1S	5000	Nat. gas	Base load
Girvin, Tex.	1-GE	5/13/54	SC-1S	5000	Nat. gas	Base load, exhaust preheats feedwater
Connecticut Light & Power Co. Thompsonville, Conn.	1-GE	9/15/53	RIC-2S	5000	Distillate	Hydro standby; peak load
Thompsonville, Conn.	1-GE	11/12/53	RIC-2S	5000	Distillate	
Danielson, Conn.	1-GE	12/11/53	RIC-2S	5000	Distillate	
Danielson, Conn.	1-GE	3/16/54	RIC-2S	5000	Distillate	
Montana-Dakota Utilities Williston, N. D.	1-GE	11/20/53	SC-1S	4000	Gas/dist.	Peak load; end of line
	1-GE	12/15/53	SC-1S	4000		
City of Larned Larned, Kans.	1-W	1955	SC-1S	1200	Gas/dist.	End of line, peak load

* Note: SC-1S, simple cycle, single shaft; RIC-2S, regenerative-intercooled cycle, two shaft; RC-2S, regenerative cycle, two shaft.

TABLE II—SINGLE-UNIT STATIONS

	Unit Size	5000 Kw Simple	5400 Kw Regenerative	15,200 Kw Regenerative	16,500 Kw Simple
1.	Structural	42,020	47,255	67,870	61,625
2.	Building services	13,575	13,915	16,375	16,375
3.	Mechanical	36,740	40,510	124,860	119,290
4.	Electrical	95,095	95,095	105,270	105,270
5.	Direct installation cost*	187,430	196,775	314,375	302,560
6.	Contractors overhead and profit on direct installation cost—32%	60,000	63,000	100,000	97,000
7.	Gas turbine generator estimating price	500,000	758,000	1,601,000	1,301,000
8.	Contractors handling charge on gas turbine-generator—5%	25,000	38,000	80,000	65,000
9.	Engineering, drafting and supervision	75,000	80,000	110,000	100,000
10.	Total estimated installed cost	$847,430	$1,135,775	$2,205,375	$1,865,560
11.	Estimated installed cost in $/kw	169.6	210.2	145.3	112.9

* This estimated cost does not include price of gas turbine-generator.

TABLE III—COMPARATIVE HEAT RATES

16,500-Kw Gas Turbine
15,625-Kw Steam Turbine

Type Unit	Station Performance—Gas Fired HR*	Gas Fired EFF†	Oil Fired HR	Oil Fired EFF
SC-1S gas turbine	16,635	20.52	16,255	21.00
RC-1S gas turbine	13,045	26.16	12,705	26.86
850 G-900 F-2 in.	12,070	28.25	11,570	29.50
1250 G-900 F-2 in.	11,549	29.55	11,070	30.85
1450 G-900 F-2 in.	11,286	30.25	10,819	31.50

* Heat rates in Btu per kwhr based on HHV.
† Efficiencies in per cent based on HHV.

load plants is beyond the scope of this paper. However, our studies show that on most systems with sharp peak loads of short duration, it is advantageous to install a certain proportion of the maximum system capacity in gas turbines. The amount of capacity in such gas turbine installations depends, naturally, on a number of factors. The magnitude and duration of the peaks, the size and thermal efficiency of the other units on the system, comparative installed costs, capital charges, all influence the decision as to whether gas turbines should be installed to meet a specific situation.

In addition, the type of gas turbine to choose must be considered. Domestic gas turbines are at present available as simple-cycle, single-shaft units; simple-cycle, two-shaft units; regenerative-cycle, single-shaft units; and regenerative-cycle, two-shaft units. Each of these have their own particular characteristics and advantages; but for peak-load plants, the extra cost of the two-shaft units can probably never be justified. Their ability to run the output shaft at variable speed is of no use, and their lower fuel consumption at low loads will hardly be taken advantage of. The choice between a simple-cycle and a regenerative-cycle machine depends upon the expected fuel costs and load factor; the regenerative unit will, in some cases, pay off its additional cost in fuel savings in a short time.

Water Injection

Since in either a standby or peak-load plant capital costs are a major part of the total cost of generating power, there has been a very definite incentive to secure the maximum output from a gas turbine at a minimum cost. In looking for ways to achieve this objective, the possibility of injecting water into the cycle between the compressor and turbine appears attractive. The increase in weight flow through the turbine and the higher Btu per pound of the water-air mixture, without a corresponding increase in the work of compression, results in about $4^1/_2$ per cent increase in useful output for each 1 per cent of water injected. Since this is accomplished without any increase in the physical size of the machine, and it appears that water quantities up to 10 per cent by weight of the air flow may be injected, this offers an attractive means of reducing the cost per kilowatt of the installation.

Since the water is introduced into the gas path, the water must be very pure to avoid deposits in the turbine. This requires an ion-exchange, demineralizing treatment for the water, and additional capital and operating expense that must be charged against the gas turbine. The injection of water also raises the exhaust temperature of the turbine and so, in order not to encroach too far upon the rupture life of the rotor parts, operation with water injection must be limited to 1000 hr per yr. This operating limitation, however, means that water can be stored during reduced load periods when the water injection is not needed to carry the load, i.e., the unit can be operated dry, at its normal continuous rating, and the treating plant sized for the average demand. An outline of a unit modified for water injection is shown in Fig. 1. The comparable simple-cycle, single-shaft unit is shown in Fig. 2.

The injection of water to increase the capacity also results in a decrease in thermal efficiency as shown in Fig. 3. However, if the heat in the exhaust is used to generate steam in a heat recovery boiler, and the steam so generated is introduced into the cycle in place of the water, the output of the gas turbine is increased in the same way; but, since the latent heat of vaporization of the water is obtained from the turbine exhaust, the thermal efficiency is actually improved. An outline of a unit incorporating such heat recovery boilers is shown in Fig. 4 and an artist's conception of such an installation in Fig. 5.

The Evaporative Cycle

A still further method of increasing the capacity and efficiency of a gas turbine plant is by use of the evaporative cycle, a diagram of which is shown in Fig. 6. Here the air leaving the compressor is passed through an evaporator supplied with water heated by the gas turbine exhaust, and picks up moisture equal to about 5 per cent of the air by weight with a corresponding increase in output of 20 per cent. Both these latter arrangements do not require the high water purity that the water injection cycle does, and so the cost of the evaporator or heat recovery boiler must be balanced against the difference in cost of the water treatment plant and the differences in fuel consumption under the anticipated load conditions.

Combined Steam and Gas Turbine Cycle

Peak loads, of course, represent only a small, although important, part of the demands on a generating system. By far, the major part of the generating capacity must be in base load units, and for these, high thermal efficiencies can nearly always be economically justified. In this field, the large steam plant, with large units of high overall efficiency, reigns supreme. Even here

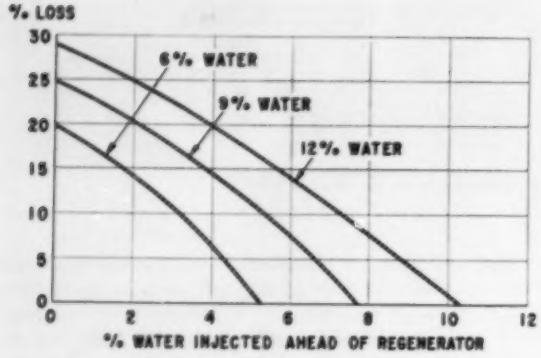

Fig. 3—Efficiency loss with water injection

though, we believe the gas turbine has a place; not alone, but combined with the steam cycle to achieve a gain in efficiency at a comparable cost per kilowatt.

Since a gas turbine operates at a higher initial temperature than any existing or prospective steam turbine plant, there is obviously a thermodynamic advantage if it could be combined with a conventional steam cycle in such a way as to utilize the high temperature features of the gas turbine, and at the same time reject the heat in the gas turbine exhaust at a low temperature level. There are several arrangements of steam and gas turbines that will accomplish this, each of which has certain advantages.

Brown-Boveri's "Velox Boiler" was perhaps the first application of a gas turbine to a steam cycle; but the limited initial temperature of their gas turbine, resulting in little or no gas turbine net output, resulted in little gain in thermal efficiency. Still, there are a large number of such installations in the world; mostly in industrial plants.

In this country, the first practical application of the combined steam and gas turbine cycle was at the Belle Isle Station of Oklahoma Gas and Electric Company mentioned previously (1). In this installation, the gas turbines, which are simple-cycle, single-shaft units, exhaust to feedwater heaters for the steam turbines. A large portion of the exhaust heat of the gas turbines is thus returned to the cycle, the extraction from the steam turbines being reduced with a corresponding increase in output for a given throttle flow. The capacity of the station increased about 25 per cent with an overall improvement in the station heat rate. This arrangement does not give the maximum possible thermal efficiency, but it can be readily applied to an existing station, and so is very attractive wherever an increase in plant capacity, an improvement in efficiency and minimum change is desired.

The use of heat recovery boilers is well known, and these can readily be applied to a gas turbine installation, either initially or at a later date. Such an installation can be economically justified whenever there is a need for steam at pressures and temperatures available from such a boiler. The maximum steam conditions available are about 600 psig-750 F, but the boiler cost for these conditions is somewhat high and may not be justified unless fuel is expensive.

The simple heat recovery boiler may be considered as only a first step in a combined cycle arrangement. Since the steam conditions available are rather low, it does not

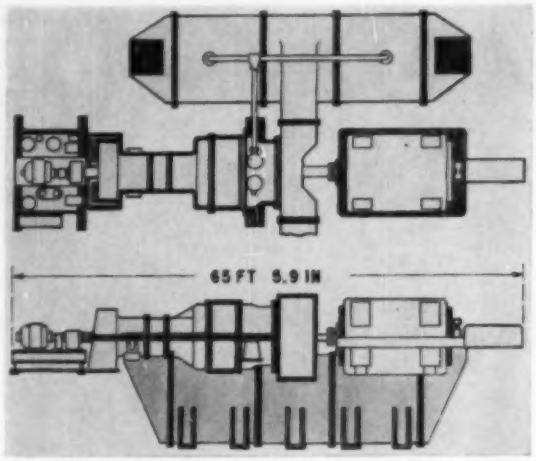

Fig. 4—Steam injection, single-shaft gas turbine with boilers, 22,700 kw

lend itself to an efficient combined steam and gas turbine plant due to the low thermal efficiency of the steam cycle. A further step is to add another separately fired boiler in which steam is also generated, and in which this steam, plus the steam generated in the heat recovery boiler, is superheated to supply a steam turbine. This arrangement allows the use of a wide variety of fuels in the direct fired boiler, and the overall plant heat rate is, of course, quite good.

If steam is required at a higher pressure of temperature than is available from a simple heat recovery boiler, supplemental firing, in which additional fuel is burned under the boiler, may be used. However, since the exhaust from a gas turbine still contains approximately 80 per cent of its original oxygen, a much larger quantity of steam, at any desired temperature and pressure can be generated by properly designing the boiler to use the exhaust from the gas turbine as combustion air and firing the necessary additional fuel under the boiler up to the limit of the available oxygen.

This arrangement, as applied to a 40,000-kw combined steam and gas turbine plant, is shown in Fig. 7. Such a plant has a heat rate $4^1/_2$ per cent lower than a conventional steam plant of the same rating with the same steam conditions. This gain is achieved with a stand-

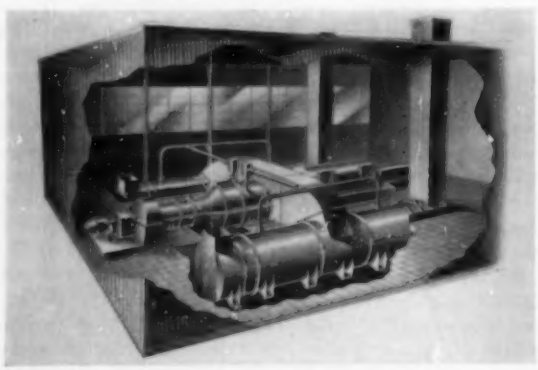

Fig. 5—Artist's conception of steam injection gas turbine-generator unit

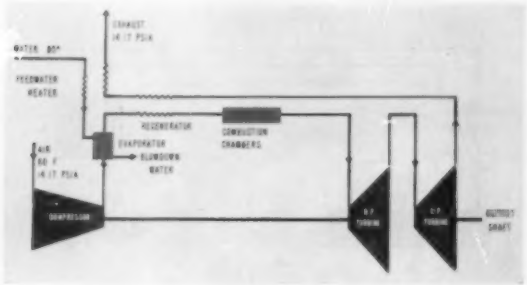

Fig. 6—Schematic diagram evaporative-regenerative cycle

ard gas turbine and an essentially standard pressurized boiler. Again, the thermal gain is not the maximum that can be obtained with a combined cycle, but any available fuel can be fired in the main boiler and only that 20 to 25 per cent of the fuel that is fired in the gas turbine need be gaseous or liquid. A comparison of the plant heat rates for this plant and a conventional steam plant are shown in Fig. 8 for a load range. The improvement in performance is quite striking and the installed costs should be economically attractive.

The Supercharged Boiler Cycle

The final step in this progression is the supercharged boiler cycle. Basically, this is the "Velox Boiler," but with the gas turbine operated at a sufficiently high temperature, 1450 F, to produce 15 to 18 per cent of the plant output, and with the necessary heat recovery equipment such as air preheaters, economizers and stack gas coolers to realize a 5 to 9 per cent improvement in thermal efficiency and corresponding heat rate.

The major boiler companies and the gas turbine builders have been studying this cycle intensively for about two years now, and are convinced of its merits and that it has a potential future equal to that of reheat. We are in about the same position with respect to this cycle as we were with respect to steam turbine reheat applications six or seven years ago.

I would like to discuss this cycle in some detail as we believe it is of considerable importance and should be of interest to all. Considering first the thermodynamic aspects; I will not go into the reasons for the thermodynamic gains, except to point out that we are essentially "topping" a given steam cycle with a higher temperature gas turbine cycle with the heat rejections at the same temperature level as before, so that there is a resulting net gain in efficiency.

Heat Balances

In practice, this can best be illustrated by the corresponding heat balance diagrams. Fig. 9 is the diagram for a conventional 100,000-kw steam turbine cycle, with steam conditions of 1800 psig-1000/1000 F-1$^1/_2$-in. Hg which we will take as our base. In adding a gas turbine supercharging a boiler, to such a cycle, the heat rejected from the gas turbine exhaust must be utilized as far as possible in the cycle. There are only two "sinks" readily available; one, the combustion air to the boiler, and two, the feedwater between the condenser and the boiler. These can be used either together or individually, and there are a large number of possible arrangements (2). Of these, three have been selected for study and comparison and the corresponding heat balance diagrams are shown in Figs. 10, 11 and 12. Fig. 10 is for a cycle with no air preheater, all the heat being absorbed in the feedwater, in two sections, an economizer section that heats the feedwater after it leaves the top extraction heater on the way to the boiler, the other, a "stack gas cooler" that replaces one of the extraction feedwater heaters and cools the exhaust gases to 300 F before they are released up the stack. Fig. 11 is similar, except that an air preheater has been added ahead of the economizer to return part of the exhaust heat directly to the boiler. The air preheater is assumed to have a 30 per cent effectiveness. Fig. 12 is the same as Fig. 11 except the air preheater has a 70 per cent effectiveness. All comparisons are made on the basis of 300 F stack temperature.

Similar heat balances have been worked out at half load, and Table IV gives the comparative station heat rates based on net station sendout. It will be seen that there is considerable advantage heat-ratewise in using an air preheater, but the overall economics may not justify its use. The tabulation includes a half-load heat rate at 1200 F to the gas turbine to indicate the effect of reduced inlet temperature corresponding to the proposed boiler characteristics.

The heat balances shown are based on gas as a fuel. Similar calculations have been made for Bunker "C" oil and Figs. 13, 14, and 15, show station heat rates vs.

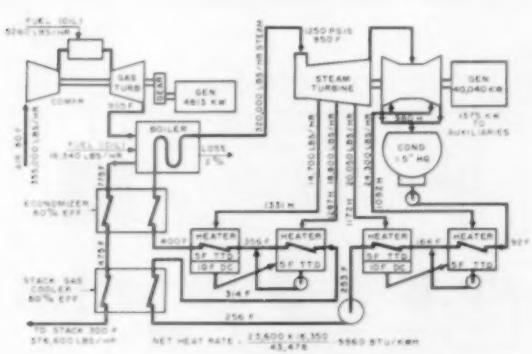

Fig. 7—Combined steam-gas turbine plant exhaust heat recovery cycle

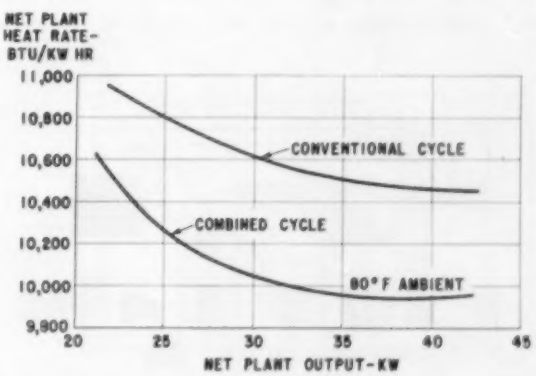

Fig. 8—Combined steam-gas turbine plant comparative heat rates. Conventional vs. exhaust heat recovery cycle

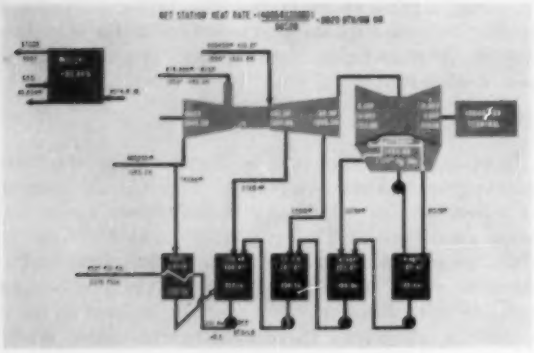

Fig. 9—Heat balance diagram; conventional gas-fired plant

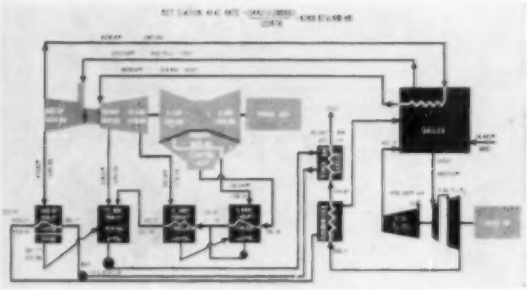

Fig. 10—Heat balance diagram; supercharged combined plant gas fired, no air preheater, above

load for a conventional and supercharged gas-fired plant, a conventional and supercharged oil-fired plant, and a comparison of oil- and gas-fired supercharged plants, respectively. Fig. 16 shows the gain in station heat rate plotted against per cent maximum load for gas- and oil-fired supercharged boiler plants as compared to a conventional plant. All these curves are for plants with 100,000-kw reheat steam turbines and steam conditions of 1800 psig-1000/1000 F-$1^1/_2$-in. Hg.

Performances for other sizes of plants, and other steam conditions, have been worked out and still other comparisons could be made, including ones for other heater arrangements (2). However, it is not necessary to discuss all these variations here. In studying this cycle, however, we have come to some general conclusions which I think are worth while to list. They are:

1. For a reheat plant, an increase in excess air from 10 to 70 per cent results in $^1/_4$ per cent poorer performance with feedwater temperatures above 450 F and $^1/_{10}$ per cent better performance at 400 F feedwater temperature.
2. The heat rate of the combined cycle is a minimum for feedwater temperatures between 400 and 450 F, but the gain relative to a conventional cycle increases as feedwater temperature decreases.
3. An increase in stack temperature of the combined cycle from 250 to 300 F results in about 0.05 per cent poorer heat rate and from 300 to 350 F in about 0.33 per cent poorer heat rate.
4. For the combined cycle, a change in ambient temperature of ±20 F results in a ±0.1 per cent change in heat rate.
5. With 1450 F, gas turbine inlet temperature and 5.4:1 pressure ratio, a 1 per cent change in the gross turbine heat-rate results in a corresponding 0.92 per cent change in the combined cycle heat rate.

Thus, we can say that the net station heat rate of a combined steam and gas turbine plant is relatively insensitive to variations in excess air, ambient temperature, stack gas temperature and feedwater temperature.

Cycle Economics

The overall economics of the combined cycle are not so clear. Studies have been made (2) which indicate a combined plant can be installed for less per kilowatt then a conventional steam plant. We have made, and are continuing to make, studies to try and determine the economics of this cycle. As far as we can tell at present, any increase in plant cost can be justified by the fuel savings that are possibe; but a careful appraisal should be made of each proposed installation. If, as is hoped, and in some quarters predicted, a supercharged boiler will not exceed the cost of a conventional boiler, then there is little doubt that such a plant will be attractive to most power companies. As always though, the final verdict must await the construction of a sufficient number of plants to get a fair comparison.

A final word as to fuels. Natural gas is, of course, the cleanest fuel available, and where its cost and continuity of supply are favorable, it makes an ideal fuel for a supercharged boiler plant. A plant for this fuel could be undertaken today, with no hesitation as to its practicability and reliability. Distillate fuels are in almost the same class; but their cost rules them out except for emergency use in a plant that normally burns gas. Bunker "C" or other residual oils are undoubtedly practical, but

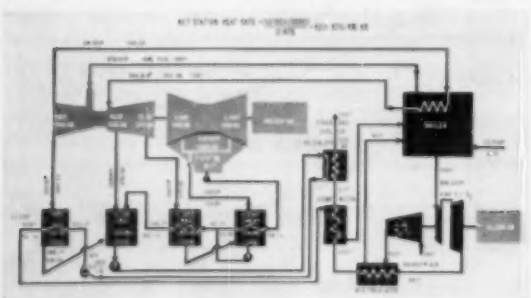

Fig. 11—Heat balance diagram, supercharged combined plant gas fired, 30 per cent effective air preheater

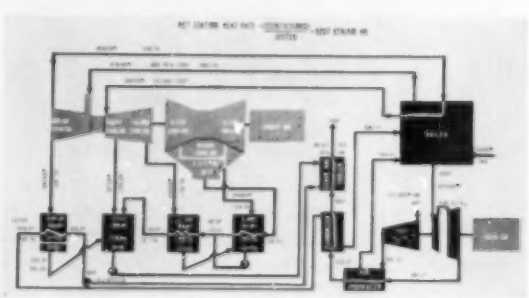

Fig. 12—Heat balance diagram; supercharged combined plant gas fired, 70 per cent effective air preheater

TABLE IV—COMPARATIVE HEAT RATES

Conventional vs. Supercharged Combined Cycle

Steam Conditions 1800 psig-1000/1000 F-1½-in. Hg. Temperature 1450 F Gas Turbine Inlet

	Gas Fired Full Load	Half Load
Conventional reheat steam plant	9920 Btu/kwhr*	10,275 Btu/kwhr
Combined cycle		
No air preheater	9269	9,367
No air preheater—1200 F gas temp.		9,637
30% effective air preheater	9221	9,371
70% effective air preheater	9207	

* All heat rates are with a 100,000-kw, TC-DF steam turbine.

there may be some unexpected problems in the boiler. For the present, it is deemed necessary to consider only oils that meet specifications as to sodium/vanadium ratio or can be treated to meet such specifications. With this limitation, residual fuels can be considered for a supercharged boiler plant.

When we come to the third, and most important fuel, coal, the situation is different. Everyone recognizes that if the supercharged boiler is to come into general use, it must be able to burn coal. At present, we do not know how to do this. Work is proceeding to solve the problems connected with coal combustion under pressure and passing the resulting products through a gas turbine. That they will be solved and the erosion, corrosion and deposit brought under control, we are confident, but it will be years before it can be offered commercially.

In addition to the various ways in which a gas turbine can be applied to power generation that have been discussed so far, there are two other ways that are worth mentioning. The first is the use of a gas turbine for boiler feed pump drive. In modern stations, with turbine units of 200,000 kw and more, the boiler feed pump power required is considerable, and a gas turbine of suitable size offers a convenient, flexible drive which, by exhausting the turbine to the boiler to furnish preheated air, will at the same time improve the overall stations heat rate and net station capability. The resulting cost per kilowatt and return on investment is attractive.

The second, can only be applied where high-pressure (600 psig or more) gas is supplied to the station. This is the use of a "flow-gas-turbine" which is used as a reducing valve; but generates a sizable amount of power. This use is of rather limited application; but does illustrate the extreme flexibility of gas turbine application. The cycle is shown on Fig. 17 and the arrangement of the

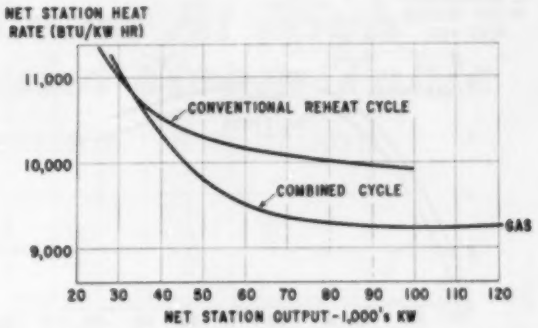

Fig. 13—Comparative plant heat rates; combined and contional cycles, gas fired

flow-gas-turbine on the shaft of conventional gas turbine which supplies heat to the incoming gas supply can be seen. This arrangement also gives an increase in station capacity with a small improvement in heat rate.

To sum up, the future place of the gas turbine in the power generation field seems assured. Its simplicity, adaptability and flexibility, coupled with its low installed cost per kilowatt and good efficiency when its exhaust heat can be recovered make it advantageous in a wide variety of applications. Its characteristics can be tailored to fit the need, and the need is there.

Manufacturers at home and abroad are investing millions of dollars in the future of the gas turbine, and we are confident a large share of that future is in central station or large industrial power generation applications.

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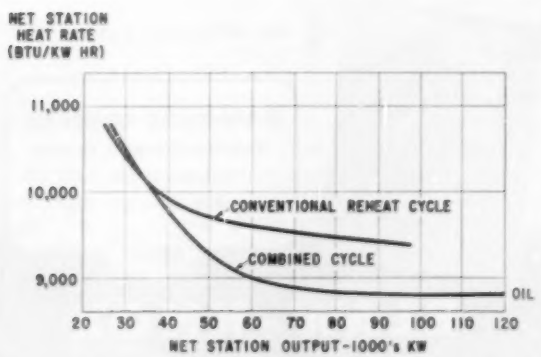

Fig. 14—Comparative plant heat rates; combined and conventional cycles, oil fired

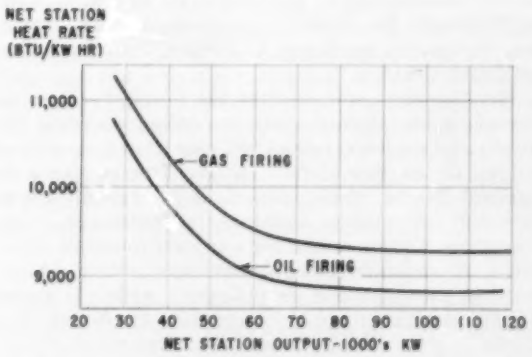

Fig. 15—Plant heat-rate comparison, oil- and gas-fired combined cycles; 1800 psig/1000 F/1000 F/1½-in. Hg abs

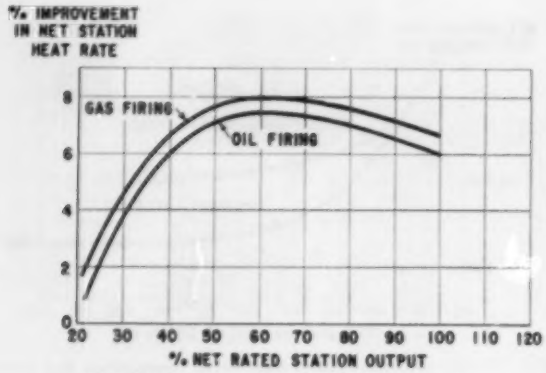

Fig. 16—Improvement in plant heat rate

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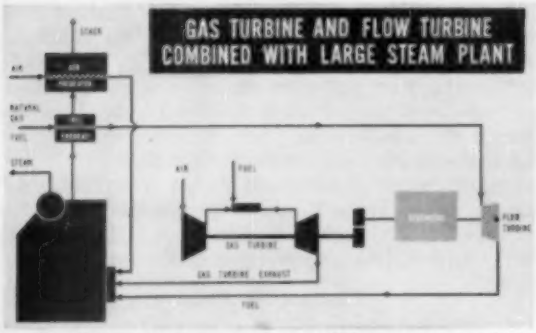
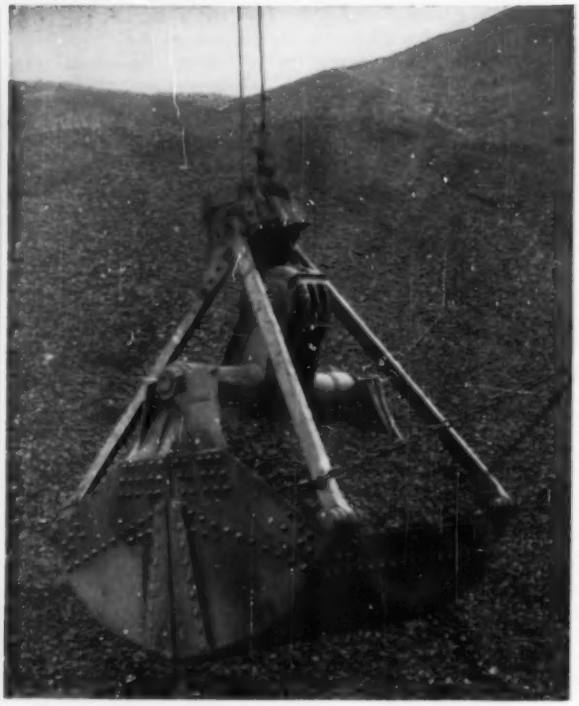


Fig. 17—Where high-pressure gas (600 psig) is supplied a flow-gas-turbine can be used as a reducing valve for gas flow and in the process generate a sizable amount of power

Air Pollution Engineers Meet in Buffalo

Beginning May 21 and carrying through May 26 the Air Pollution Control Assn., successor to the Smoke Prevention Assn. of America, met, roughly 700 to 800 strong, in its 49th international get-together in Buffalo, N. Y. In addition to a detailed technical program a number of special luncheons and banquets were scheduled. One of the highlights was the conferring of the nation's two top awards in connection with control of air pollution. They were granted to Ward F. Davidson of Port Washington, N. Y., and Dr. Edward R. Weidlein of Pittsburgh, Pa., by the Association's Awards Committee, chairmaned by Henry F. Hebley, Pittsburgh Consolidation Coal Co.

Mr. Davidson, who received the Frank A. Chambers Award, is an internationally recognized electrical and mechanical engineer, retired last year from Consolidated Edison Co. of New York. Dr. Weidlein, receiving the Richard Beatty Mellon Award, is the recently-retired president of Mellon Institute in Pittsburgh. The Chambers Award, named for a pioneer in smoke abatement, is awarded annually "for outstanding achievement in the control of air pollution" while the annual Mellon Award in honor of the late Pittsburgh civic leader is given to one "whose contributions of a civic, administrative, technical or other nature have aided substantially in the cause of air pollution control".



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Properties of Steam At High Pressures—An Interim Steam Table*

By R. C. SPENCER† C. A. MEYER†† R. D. BAIRD†††

During the past years the steam conditions considered for central station steam generation and chemical process plants have increased above the limits of experimental investigations and lately above the extrapolations contained in currently published steam tables. The table described in this paper is a reasonable and consistent extension of the Keenan and Keyes steam tables into the region of 5500–10,000 psia and 32–1600 F and will be useful in power systems calculations until tables by the ASME Steam Properties Research Project are available.

TO fill the need for accurate high pressure and high temperature steam properties beyond the extrapolations in currently published steam tables, the ASME, through a Technical and a Research Committee is undertaking as part of an international program the task of directing and coordinating the 4 to 6 years of experimental work leading to an authoritative steam table to 15,000 psia and 1500 F. This program is well described in the ASME publication "Steam Properties Research" (1).[1]

However, during the 4- to 6-year period required to develop the authoritative table, it would be desirable to have an industry-wide accepted table covering the high pressure region which would be essentially correct from an engineering viewpoint. With this end in mind the Power Division of ASME formed a Subcommittee for the express purpose of preparing such an interim steam table.

The Subcommittee delineated the range of this interim steam table as 5500 to 10,000 psia and 32 to 1600 F. The Subcommittee also stated that the table should be prepared in the most expeditious manner possible by making use of any presently available tables and should, if possible, join smoothly some currently published table for the lower pressure regions. The reason for establishing data in the low temperature high pressure region is primarily because of the increased importance of boiler feed pump work on steam cycle efficiency as pressure is increased in central station power plants. This paper contains a description of what has been done.

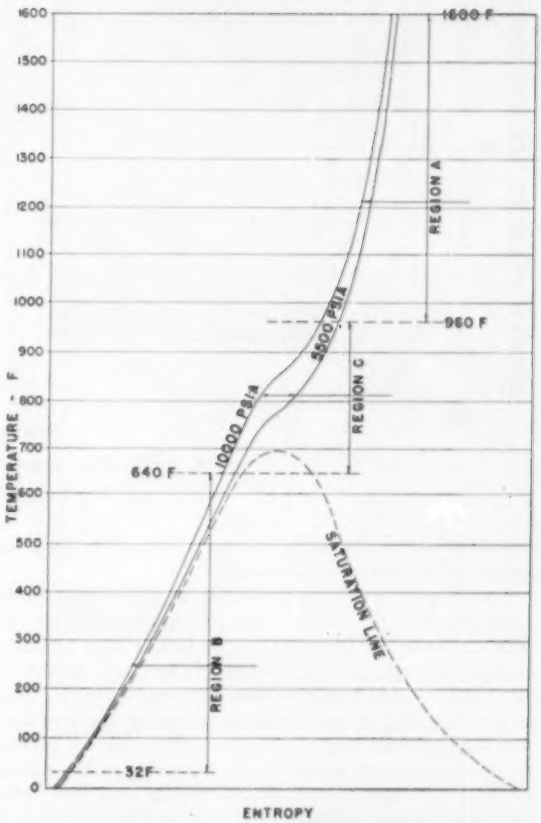

FIG. 1
TEMPERATURE-ENTROPY DIAGRAM SHOWING AREA COVERED BY THE INTERIM STEAM TABLES. (NOT TO SCALE)

The resulting table, however, can be obtained through the ASME, 29 W. 39th St., New York 16, N. Y.

The authors wish to emphasize that the interim steam table presented at this time is not based upon any new data, and will probably be proved to be somewhat in error when the experimental results are obtained from the ASME Steam Properties Research Project and other new work. The sole purpose of this interim table is to provide a consistent and reasonable extrapolation of current tables that will be useful in power system calculations until better data are available.

Development of the Table

The area covered by the interim steam table was divided into three regions as shown in Fig. 1 and the

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* Paper presented before the Semi-Annual Meeting of the American Society of Mechanical Engineers, Cleveland, Ohio, June 18–20, 1956. The interim steam table itself is not reproduced here but may be obtained from the ASME 29 West 39th St., New York 16, N. Y. Order Dept. $1.00.

† Large Steam Turbine-Generator Department, General Electric Company, Schenectady, New York.
†† Steam Division, Westinghouse Electric Corporation, Philadelphia, Pennsylvania.
††† Steam Turbine Department, Allis-Chalmers Manufacturing Co., Milwaukee, Wisconsin.

[1] Numbers in parentheses refer to similarly numbered references in the bibliography at the end of the paper.

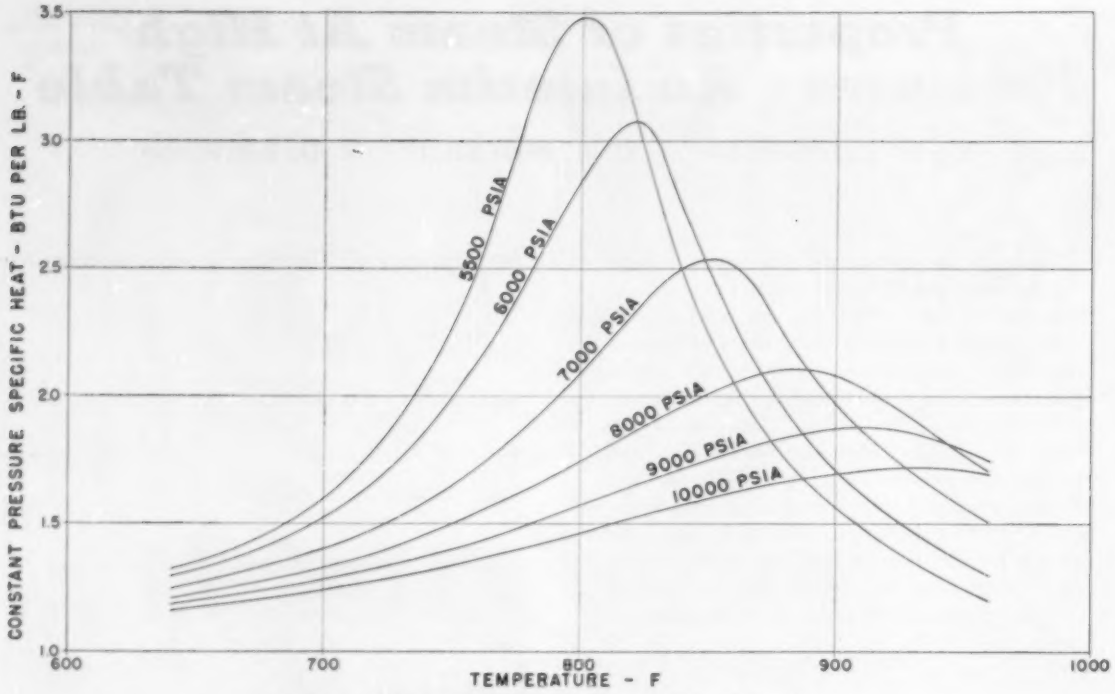

Fig. 2—Constant pressure-specific heats for Region C

development of the table for each region is fully described in the following sections.

A review of currently available high pressure tables indicated that the table developed by the United Aircraft Corporation (2) would serve in the high temperature-pressure region, "A," Fig. 1. There appeared to be no available table in the low temperature–high pressure region and it was therefore necessary to develop a new table for this region. Further investigation pointed out that problems would be encountered in the middle temperature region, "C," of 640–960 F due to unusual inflections in the enthalpy data. Therefore, this middle region was treated separately from the low temperature region "B" in developing the new data.

Region A—960 to 1600 F

The United Aircraft Corporation (2) tables, which were based upon the experimental results of Kennedy, extend from 840 to 1600 F and the authors originally intended to use them to the lower temperature level. However, further investigation in the 840 to 960 F region indicated that the United Aircraft Corporation isobars of an enthalpy-temperature diagram had double inflection points. Since the slope of these isobars is directly proportional to the specific heat, this double inflection results in the specific heat curve having a double maximum within a relatively small temperature range. A brief discussion of this phenomenon is contained in Reference (3). The United Aircraft Corporation tables were not used below the somewhat arbitrarily selected temperature of 960 F because it does not seem probable that water substance would actually have this double inflection characteristic.

To satisfy the criteria that the interim table should join a currently published steam table in a smooth manner the authors elected to make the interim table consistent in level, and join smoothly with the Keenan and Keyes (4) tables along the 5500 psia line. Since the United Aircraft Corporation data and the Keenan and Keyes data differ at 5500 psia it was necessary to arbitrarily change the United Aircraft Corporation level at 5500 psia to that of the Keenan and Keyes data and then fair the correction into the United Aircraft Corporation table. This fairing was done in the 5600 to 5900 psia range.

Also, since the original United Aircraft Corporation table contained data at 100 psia increments (and also at 1300 and 1500 F) it was felt desirable to include these data in the interim table, although a pressure increment of 500 psia was used in the remainder of the table.

The reader is referred to the United Aircraft Corporation (2) report for a comprehensive description of the development of their equation of state and steam table.

Region B—32 to 640 F

In the region below 960 F there was no table available, such as the United Aircraft Corporation table, that could be adapted for use in the interim steam table. Therefore, a table has been developed by the authors using graphical and numerical methods. First, a graphical plot of volume vs. pressure and temperature was made for this region using the boundary data of Keenan and Keyes and the high pressure compressed liquid data of Amagat (5) as a guide. These volume data were cross plotted in several ways until a smooth family of volume curves was developed. The volume data were then differentiated and integrated numerically using the methods described in Appendix A through C to deter-

mine the change in entropy and enthalpy at constant temperature from the 5500 psia level. The usual problems encountered in obtaining smooth results with numerical methods of this type were overcome to the necessary degree by smoothing the basic volume data to the required significant figures. The calculated changes in entropy and enthalpy were added to the Keenan and Keyes 5500 psia values. Since the Keenan and Keyes tables contain values at widely spaced intervals (100 F) in this region it was necessary to numerically interpolate as described in Appendix D to obtain values at the desired interval of 10 or 20 F. The numerical calculations were carried out on a high speed electronic computer.

As mentioned under Region A, the area between approximately 640 and 960 F has a double inflection in the isobars of an enthalpy vs. temperature diagram and it was therefore necessary to discard the data above 640 F obtained by the above method.

Region C—640 to 960 F

One way of obtaining a table for this area would have been to redraw the volume curves and repeat the numerical procedure used for Region B. However, since it was desirable to remove the double inflection from the isobars of an enthalpy vs. temperature plot, it was decided to arbitrarily draw a family of enthalpy curves that suited the boundary conditions and also gave a smooth family of specific heat curves. The specific heat curves derived from the arbitrarily drawn enthalpy curves are shown in Fig. 2. The total area allowable under any one of the isobars in this figure is fixed by the boundary conditions at 640 and 960 F. However, the distribution of the area over this interval is determined by the shape of the enthalpy curves.

With a table of enthalpies it was then possible to determine entropies by using the approximate relationship of $(\Delta S)_p = (\Delta H/\Delta T)_p$ and adding the incremental values to the value at 640 F. Errors due to the approximate nature of this calculation were apparent when the entropy calculated by the above manner at 960 F was compared with the entropy at 960 F obtained from the United Aircraft Corporation (2) tables. Any difference was then distributed over the interval.

The determination of volumes was at first attempted by an inverse of the procedure used to determine entropy in Region B (see Appendix A, equation 2). However, it was found that the entropy data were not sufficiently smooth to give smooth volumes and therefore the volumes so obtained were used only to determine an approximate level. Once an approximate volume level had been established a family of curves was drawn as shown in Fig. 3 and used to obtain tabular values.

These volumes were checked by calculating enthalpy and entropy with the Region B method and found to be within the accuracy necessary for the usual engineering calculations and additional effort was not felt justified due to the improbable use of this region of the steam chart.

Conclusions

The result is a useful, consistent extension of the Keenan and Keyes steam tables into the high pressure regions that are being investigated for modern steam power and chemical plants. While considerable more effort could have been expended in determining a completely consistent thermodynamic set of data, it was not felt that the effort was justified, since any table not based upon experimental results will be subject to revision when such data are available.

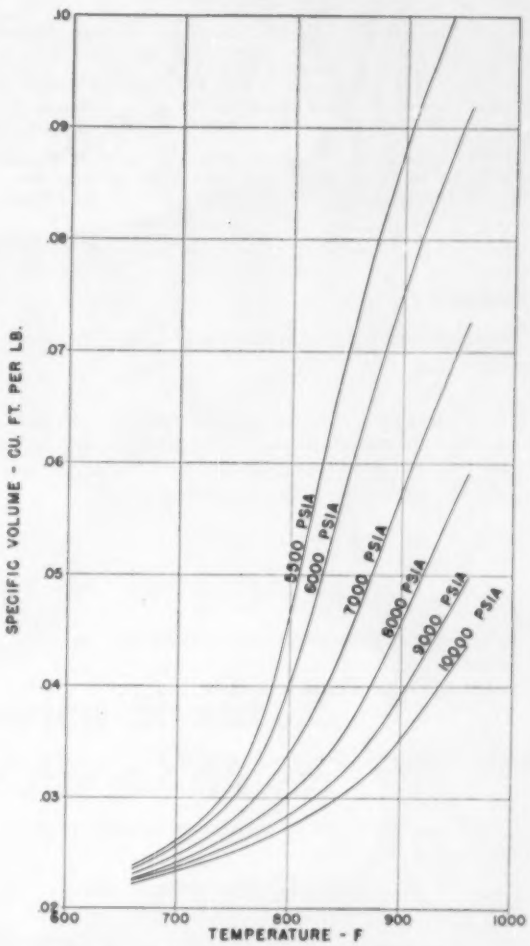

Fig. 3.—Specific volumes for Region C

Acknowledgments

The authors wish to express their appreciation for the inspiration and guidance of the members of the Subcommittee on Interim Steam Tables; Messrs. P. H. Knowlton, C. C. Franck and H. D. Emmert. Also the permission of the United Aircraft Corporation to publish their high temperature data is greatfully acknowledged. Without these excellent tables our task would have been considerably greater. To Mr. H. C. Schnackel of the General Electric Company, Messrs. G. J. Silvestri and W. G. Steltz of Westinghouse Electric Corporation and Mr. J. S. Barker of the Allis-Chalmers Manufacturing Company goes much of the credit for our success in completing the task in a very short time.

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APPENDIX

A. Equations for Determining H and S from the P-V-T Data

The Maxwell relation (equation 1) may be evaluated at constant temperature and integrated to obtain the change in entropy at that temperature between the base and desired pressure.

$$\left(\frac{\partial s}{\partial p}\right)_T = -\left(\frac{\partial v}{\partial T}\right)_p \tag{1}$$

$$(S - S_o)_T = -\int_{P_o}^{P}\left(\frac{\partial v}{\partial T}\right)_p dp \Big|_T \tag{2}$$

A corresponding expression for enthalpy may be derived as follows:

The relation for a pure substance

$$du = Tds - pdv \tag{3}$$

may be transformed into the equation

$$dh = Tds + vdp$$

Dividing this expression by the change in pressure to get, at constant temperature

$$\left(\frac{\partial h}{\partial p}\right)_T = v + T\left(\frac{\partial S}{\partial p}\right)_T \tag{4}$$

From (1) we may substitute a volume derivative for the entropy derivative and obtain:

$$\left(\frac{\partial h}{\partial p}\right)_T = v - T\left(\frac{\partial v}{\partial T}\right)_p \tag{5}$$

A convenient form for future use is:

$$(h - h_o)_T = \int_{p_o}^{p} vdp - T(S - S_o)\Big|_T \tag{6}$$

where

s = entropy
h = enthalpy
T = temperature
p = pressure
v = volume

Subscript o = reference conditions.

Equations (2) and (6) were used to determine the changes in entropy and enthalpy from 5500 psia between 32 F and 840 F.

B. Numerical Method of Differentiation to Determine $(\partial v/\partial T)_p$

The tabular values of v vs. P, T were numerically differentiated to obtain $(\partial v/\partial T)_p$ using a method based upon Lagrangian polynomials and described in NACA reference TN 2214 (7).

The differentiation formula for the first derivative at the central point of 5 equally spaced points is in our terminology:

$$\left(\frac{\partial v}{\partial T}\right)_p = \frac{1}{\Delta T}\left[0.083333(v_{T-2\Delta T}) - 0.666666\,(v_{T-\Delta T}) + 0.666666\,(v_{T+\Delta T}) - 0.083333\,(v_{T+2\Delta T})\right] \tag{7}$$

Since this method required values two increments above and below the desired value it was necessary to extrapolate the tabular values of volume to 0 and 680 F to obtain derivative values from 40 to 640 F.

C. A numerical Method of Integration to determine $\int (\partial v/\partial T)\, dp$ and $\int v dp$

The integration for the interval from 5500 to 6000 psia was performed using the 6 point - 5th degree quadrature formula (8):

$$\int_0^1 ydx = \frac{l}{1440}\left[493y_0 + 1337y_1 - 618y_2 + 302y_3 - 83y_4 + 9y_5\right] \tag{8}$$

The remaining increments were integrated using Simpson's Rule (9):

$$\int_0^2 ydx = \frac{l}{3}\left[y_0 + 4y_1 + y_2\right] \tag{9}$$

Since Simpson's Rule evaluates the integral over two intervals the rule was applied starting from 5500 psia to obtain the Δ at the 6500, 7500, 8500 and 9500 psia levels and starting from 6000 psia to obtain the Δ at the 7000, 8000, 9000 and 10,000 psia levels.

D. A Numerical Method for Determining the 5500 PSIA Values of V, H, S.

The Keenan and Keyes tables contain values of v, h and s at 5500 psia for 100 F intervals between 100 F and 600 F. In order to obtain values at 20 F increments Newton's Formula for Forward Interpolation (9) was applied to the tabular values.

For enthalpy vs. temperature this becomes for our particular case:

$$h = h_0 + \frac{T - T_0}{\Delta T}\left[\Delta^1 h + \frac{T - T_1}{\Delta T}\left[\frac{\Delta^2 h}{2} + \frac{T - T_2}{\Delta T}\left[\frac{\Delta^3 h}{3} + \frac{T - T_3}{\Delta T}\left[\frac{\Delta^4 h}{4} + \frac{T - T_4}{\Delta T}\left[\frac{\Delta^5 h}{5}\right]\right]\right]\right]\right] \tag{10}$$

which is in continued product form useful for computer use. A similar equation may be written for entropy and volume. The 5500 psia values at 40, 60 and 80 F were obtained by an extrapolation of the difference table for the 100 to 200 F range.

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Nuclear Power Plants Discussed at ASME Pittsburgh Section Conference

MORE than 300 engineers met in Pittsburgh on April 30 and May 1 for the Tenth Annual Mechanical Engineering Conference sponsored by the ASME Pittsburgh Section on the subject of nuclear power plants. Apart from the technical sessions the highlight of the two-day meeting was the inspection trip to the Shippingport Power Station of Duquesne Light Company, this being one of the first large engineering groups to visit the site of the first American central station nuclear power plant.

An opening paper surveying types of nuclear power reactors under commercial development was presented by **Dr. W. E. Shoupp** of Westinghouse Electric Corporation. In selecting a reactor design there are more than 1000 possible choices, of which possibly 100 merit more thorough investigation. Dr. Shoupp concluded his talk with the showing of a film entitled "First in the World" which was originally presented at the Geneva Conference on the Peaceful Uses of Atomic Energy last August by the Russian government. It shows the operation of a 5000-kw experimental nuclear power plant near Moscow. The motion picture indicated that the plant was very highly instrumented for experimental purposes and research.

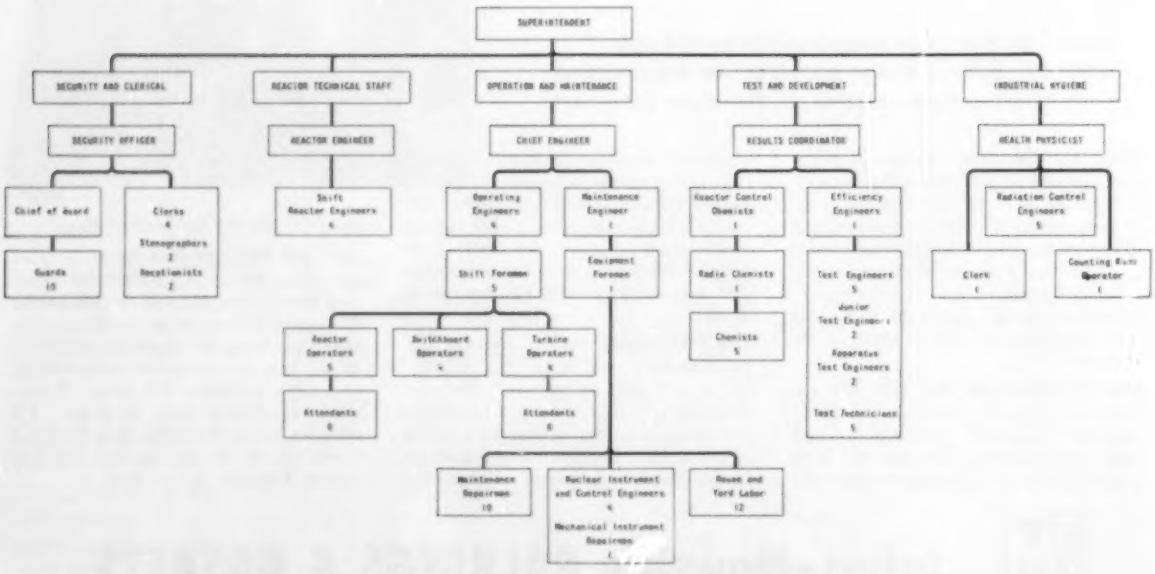
Reactor Safeguards

Dr. C. D. Luke of the Atomic Energy Commission discussed in some detail the procedures necessary to obtain a license for the commercial and industrial design and operation of a nuclear reactor. Generally a construction permit is issued before a license is granted, allowing the applicant to develop the necessary detailed information that must be filed with the AEC Reactor Safeguards Committee. It is necessary to supply considerable information to explain plans for action and safety precautions in the case of a reactor emergency. In the discussion that followed the formal paper, it was pointed out that fuel element fabrication facilities do not have to be licensed. Procedures for granting operators licenses for nuclear reactors have not been finalized, but some individuals are being trained in the National Laboratories to qualify as operators by examination or otherwise.

Central Station Staff

One of the most informative papers on the program was presented by **G. M. Oldham,** superintendent of Shippingport Station of Duquesne Light Co., on the subject of "Personnel Programs at Shippingport Station." Two factors that make the personnel problem more difficult are the absence of precedent and the lack of experience in this field on the part of employees of the power companies. It was decided to adhere insofar as possible to existing personnel policies of the company, and with few exceptions those responsible for the operation of the Shippingport Station have been selected from within the company. All the technically trained men assigned to Shippingport were given training to provide the necessary background in understanding the operation and maintenance of the nuclear power station. Much of this training was given at the Naval Reactor Research Plant at Arco, Idaho, with some additional training at the Bettis Plant of Westinghouse Electric Corporation. All personnel at the plant were given lectures on security measures and health physics, and additional training in this area will be provided at the station.

The station will be staffed by 125 persons, of which 57 are technically trained. This compares to 66 per-



Preliminary organization chart, Shippingport Station, Duquesne Light Company

sons operating a conventional station of similar capacity on the same electric system. The reasons for this large increase in personnel lie in the fact that (1) the station is the first of its kind and must establish an experience background for other nuclear power plant installations; (2) there is a greatly increased test program because of the many new types of equipment involved; and (3) it is hoped to have the station act as a pool for training manpower for other future installations. The training program began 36 months in advance of the scheduled startup of the station.

The accompanying organization chart shows the functions of members of the station staff as planned.

Professional Accomplishments

A. C. Pasini, vice president of Region V of ASME, presented an inspiring luncheon address entitled "A Few Accomplishments of Our Profession." The habit of integrity is as indispensable to an engineer as cleanliness is to a surgeon. On the other hand, many engineers are too forthright for suave politics. Mr. Pasini said that in the past too little attention has been given to the social and economic status of the engineers and urged support for the programs of the Engineers' Council for Professional Development. He particularly emphasized the necessity of carrying out the activities of ECPD at the community level by members of local engineering societies.

Valves and Pumps

Valves for nuclear plants such as the pressurized water reactor at Shippingport differ in several respects from the valves used in conventional steam plants, according to **John Thorel** of Westinghouse Atomic Equipment Department. In some sections of the plant there may be no opportunity for maintenance, so that valves must outlast the life of larger and more costly components in the system. Also the dissociation of water accompanying radiation may cause a constant stream of oxygen resulting in more potential corrosion than usual. In some cases surface finishes must be made much better than those now commercially available, and some components may have to be hermetically sealed.

A companion paper by **W. N. Wepfer,** also of Westinghouse, discussed zero leakage pumping as applied to nuclear power plants. In the discussion that followed it was pointed out that the efficiency of a canned motor pump may be on the order of 10 per cent less than that of a conventional pump, but that it is capable of performing functions in a nuclear power plant that could not be accomplished by standard equipment.

Future ASME Activities

In a banquet address entitled "ASME Must Be Awake to Possible Imports of New Science and Technology," **Joseph W. Barker,** president of the Society, analyzed some of the

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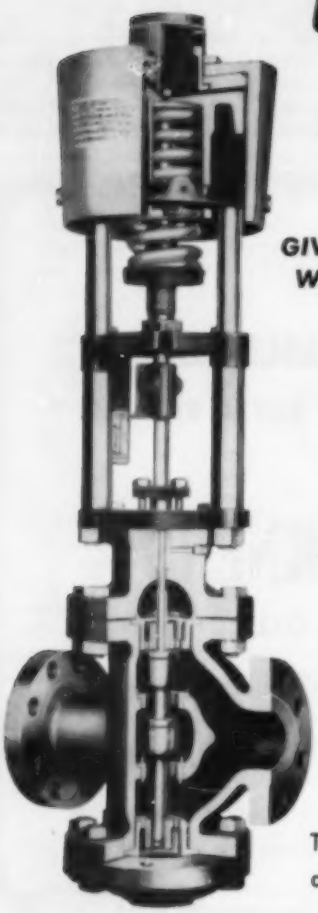

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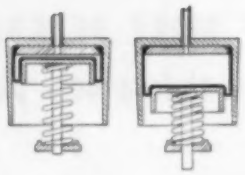

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factors which contributed to the formation of smaller technical societies which "splintered" from the four founder societies. He then raised the question as to what could be done to prevent future actions of a similar nature and to promote more unity within the profession. One step is to undertake joint pacts or agreements such as ASME recently has entered into with the American Rocket Society, with a view to sponsoring joint meetings and joint papers. On the other hand, to prevent future splintering activity ASME must be wakened to possible new impacts of science and technology. Dr. Barker mentioned the establishment of the ASME Nuclear Engineering Division as an example of recent action to satisfy specialized interest of engineers and pointed out some other specialties in which the engineering societies could profit by cooperating in joint conferences. Such areas as hydraulics, in which both ASME and ASCE have large groups; petroleum, in which ASME, AIChE and AIME share common interest; and steam power, in which both ASME and AIEE have active groups, represent opportunities for closer society collaboration in programing. With respect to the future, Dr. Barker stated he was certain that ASME should establish a

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Research Committee on Solar Energy immediately in order to anticipate the needs of its membership in this growing area of science and technology.

Water Treatment

Two papers were presented on the chemistry of pressurized water nuclear power plants. **Paul Cohen** of Westinghouse Electric Corp. emphasized the many features which nuclear and conventional power plants have in common. These include structural integrity and operational suitability, feasibility of operation and maintenance, and control and disposal of process wastes. In the Shippingport reactor the oxygen in the pressurized water circuits will be removed by hydrazine at startup and maintained at approximately neutral pH with conductivity under 1 micromho. With respect to radioactivity of solids that may be in the water, Mr. Cohen stated that substances remaining radioactive for more than 12 hours constituted more than 50 per cent of the activity following shutdown.

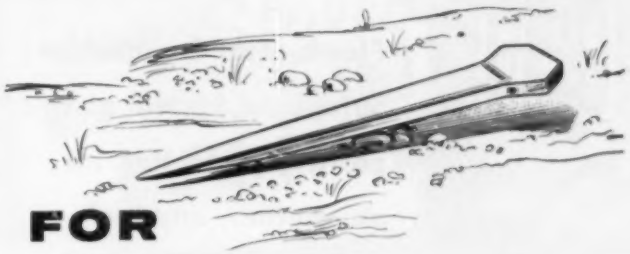
Dr. S. F. Whirl of Duquesne Light Co. emphasized some of the problems encountered in the stress corrosion behavior of stainless steels. Since much of the piping and equipment in Shippingport Station will be of stainless steel construction, extensive investigations are under way to analyze the factors involved in stress corrosion cracking and to take steps in both selection and fabrication of alloys to minimize the dangers from potential failure.

In the discussion of the two papers, mention was made that a vacuum modification of the Winkler method for oxygen measurement will be employed at the station. Development work is being carried on with the A. O. Beckman Co. in devising more precise conductivity measurements.

Startup Procedures

L. R. Love, chief engineer of Shippingport Station, outlined one of several possible startup procedures for the nuclear reactor and associated generating equipment. A high degree of oxygen removal from the reactor coolant is essential before starting the reactor coolant pumps. The coolant may then be circulated for as long as four hours at 600 psig, 190–220 F in order for the hydrazine reaction to reduce the oxygen to the desired level. Subsequently the pressurizer heaters will be started up and additional purification systems will be placed in service. Next the reactor control systems will be energized as coolant temperature is increased, and the rods withdrawn by small steps as

200-1



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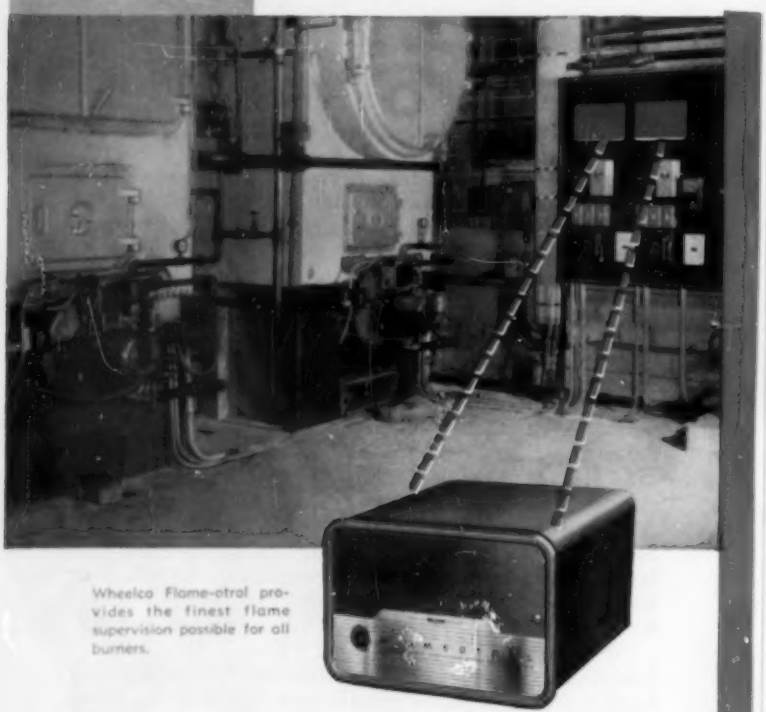

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As outlined, this procedure of start-up from cold will take approximately 8 hours. However, Mr. Love cautioned that this was but one of several possible methods of startup and that both the timing and sequence of operation may be varied as more experience is acquired.

Fuel Element Reprocessing

The final paper on the program was by **Dr. H. B. Coats** of the Blaw Knox Co., whose topic was "Reprocessing of Spent Fuel Elements from Nuclear Reactors." Costs for fuel reprocessing may well be a decisive factor in the ultimate economics of nuclear power plants, but with greater experience they may be stabilized at a much lower level than is possible during the current developmental stage. Dr. Coats mentioned the extremely wide variation in shaping, cladding and composition of fuel elements. This great variety of material greatly increases chemical reprocessing costs since it is not possible to get enough volume of any single material to justify the type of continuous processing that promotes the greatest economy. Dr. Coats expressed the belief that for some time to come a type of central processing plant capable of handling several types of material is to be preferred to a specialized processing plant at each individual nuclear power installation.

Personals

Alco Products, Inc., has announced the appointment of **Captain C. S. Seabring,** USN, as director of research and development located at Schenectady. Capt. Seabring's responsibilities will include certain aspects of

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ALCO's nuclear power projects and the company's gas turbine development program.

Directors of National Valve and Manufacturing Co. have elected **Henry Haller, Jr.,** president of the firm to succeed his father, **Henry E. Haller, Sr.,** who was named chairman of the board.

Stone & Webster Engineering Corp. has announced the election of **Edward J. Ford, Harold J. Sykes** and **Edwin H. Krieg** as vice presidents of that corporation. Mr. Ford, senior construction manager of the New York office and Mr. Sykes, construction manager in the Boston office will continue their responsibilities in the direction of construction projects of the organization in the power and industrial fields throughout the world. Mr. Krieg, who is a consulting engineer in the New York office will devote his attention to the corporation's interests in the steam power and related fields.

Obituaries

Ollison Craig, vice president of Riley Stoker Corp., died April 3 in Holy Cross Hospital at Ft. Lauderdale, Fla., where he was vacationing. He was 68. Mr. Craig became associated with Riley as a research engineer and was instrumental in the development of combustion equipment. He was named engineering manager in 1937 and became vice president in 1949.

Dr. Eugene Casson Crittenden, internationally known scientist and expert on standards of physical measurement, died of cancer March 28 at Garfield Hospital, Washington, D. C. He was 75 years of age and had been ill for several months. Dr. Crittenden had retired as associate director of the National Bureau of Standards in December 1950 but he continued to serve the Bureau as a consultant to the Director up to the time of his illness.

Franz Schmidt, associated with Allis-Chalmers hydraulic turbine department since 1906, died April 22 in Milwaukee at the age of 74. For many years, Mr. Schmidt was engineer-in-charge of hydraulic turbine design. In that capacity he was associated with some of the company's major hydraulic developments. Mr. Schmidt served as chief engineer from 1942 to 1945 when ill health contributed to his temporary retirement. Since his return in 1948 he had been consulting engineer with particular reference to rotary valves, steel castings and other hydraulic problems.

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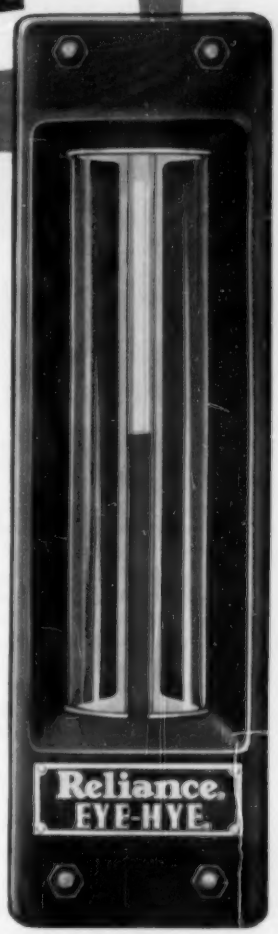

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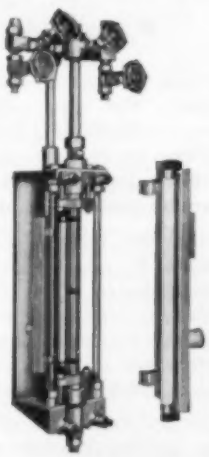

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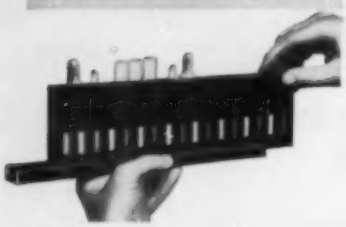

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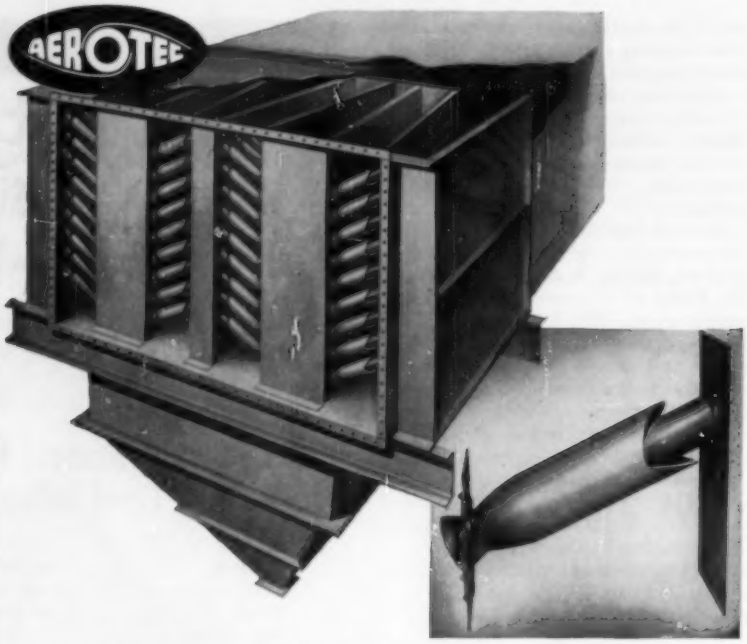

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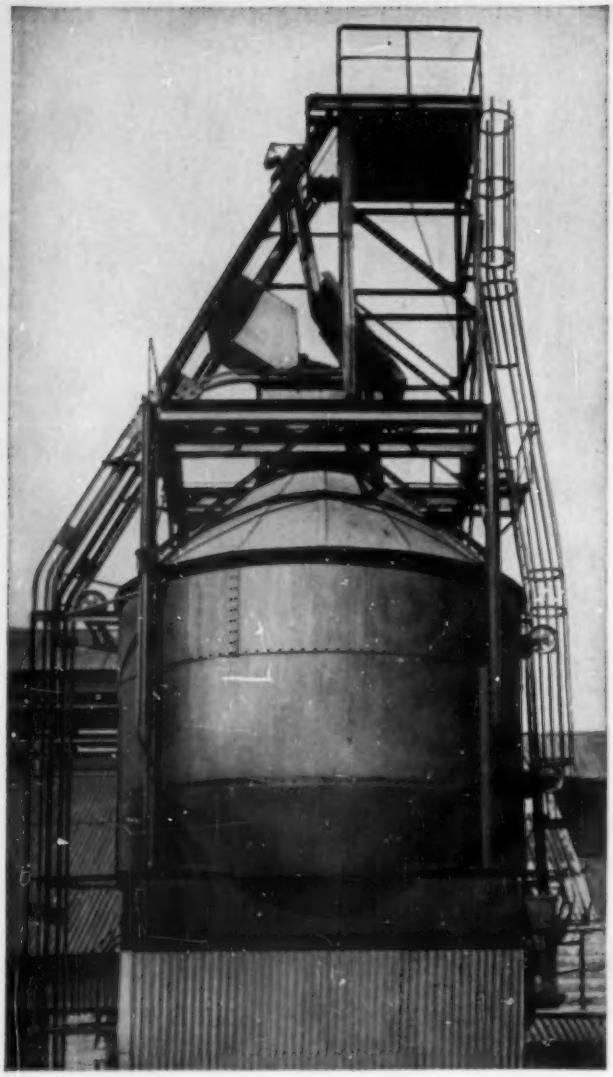

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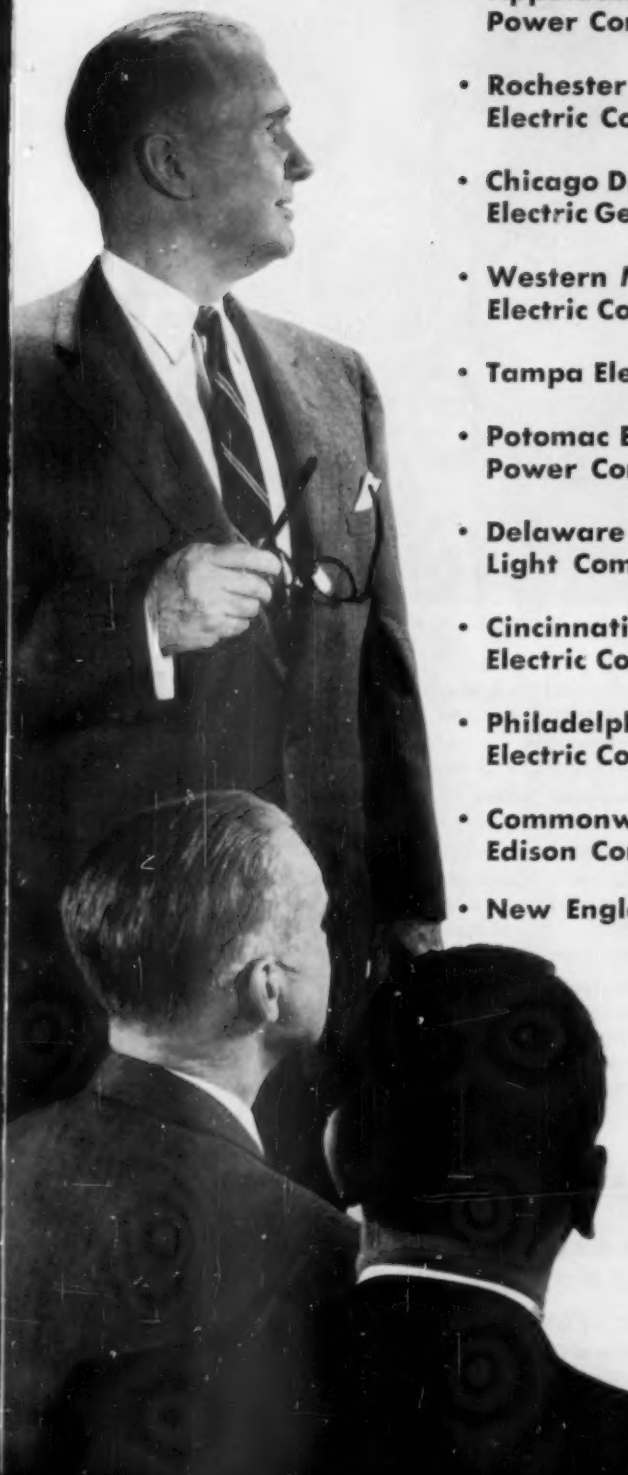

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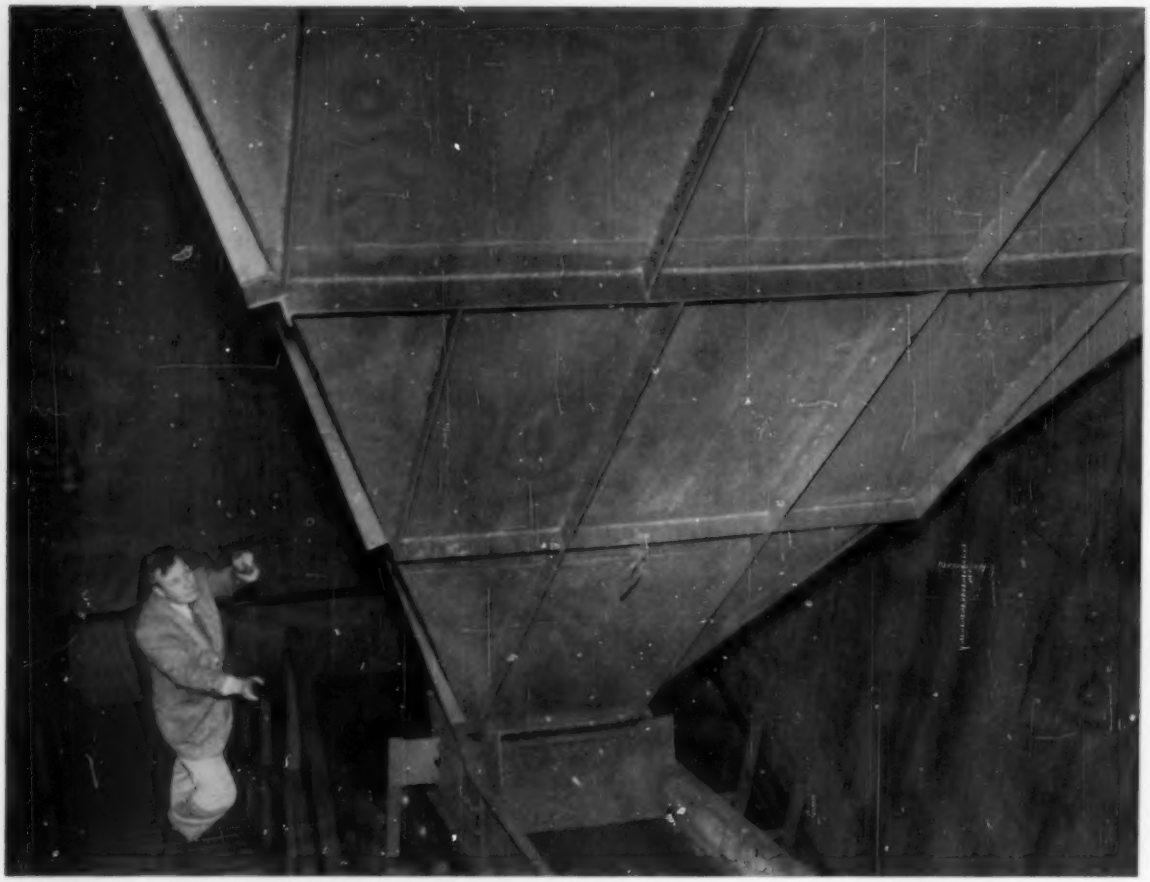

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***and only Multiclones* give vital advantages like these...**

No wonder "MULTICLONE" is the leading name in the centrifugal recovery of fly ash from all types of gases, hot or cold.

No other mechanical recovery equipment has so many years of fly ash recovery experience behind it . . . or has such uniformly high collecting efficiency . . . or provides so many other money-saving, space-saving advantages as MULTICLONE. The four advantages outlined below are by no means the complete MULTICLONE story, but are typical of the vital savings found *exclusively* in MULTICLONE equipment . . .

Uniformly High Recovery:

MULTICLONE'S multiple *small diameter* tubes—made possible by its exclusive vane design—whirl the dirty gases with greater centrifugal force, thus throwing out not only the large, medium and small particles, but also a high percentage of the *extremely small* particles of 10 microns and less. This, coupled with the fact that there are no pads or filters to become choked with recovered material, results in a more complete recovery of *all* suspended materials from the gas stream.

Long and narrow

Square

Maximum Adaptability:

In addition to its unusual compactness, the MULTICLONE is also unusually adaptable to various installation requirements. Where head room is low it can be installed with side-inlet side-outlet connections. Where side clearances are restricted, it can be installed with side-inlet top-outlet connections. In addition, without changing capacities, the shape of the unit can be varied—long and narrow, short and wide, or square—to fit restricted spaces . . . and its single-inlet single-outlet duct requirements permit greater flexibility and simpler installation. These savings slice installation costs, space requirements and insulating expense.

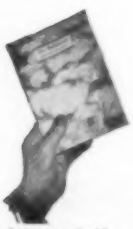
Space-Saving Compactness:

Plant space costs money—so be sure to check space requirements carefully. As shown in the accompanying chart, the MULTICLONE requires less floor space and less cubic space than any other unit of comparable capacity and performance. Translate these savings into today's high costs for plant space and you readily see the great importance of this one MULTICLONE advantage alone!

Make	Relative Space Requirements In Sq. Ft.	In Cu. Ft.
Multiclone	1.0	1.0
Collector A	2.1	1.8
Collector B	5.9	3.2
Collector C	6.8	3.9

Minimum Maintenance:

The MULTICLONE has no high speed moving parts to repair or replace... no pads or filters to clean or renew... nothing to choke the gas flow or increase draft losses as suspended materials are recovered. MULTICLONE draft losses remain uniformly low *at all times*. Further, the recovered material from an entire bank of tubes is collected in a *single* hopper—far easier to service and maintain than the multiple hoppers of conventional cyclone units.



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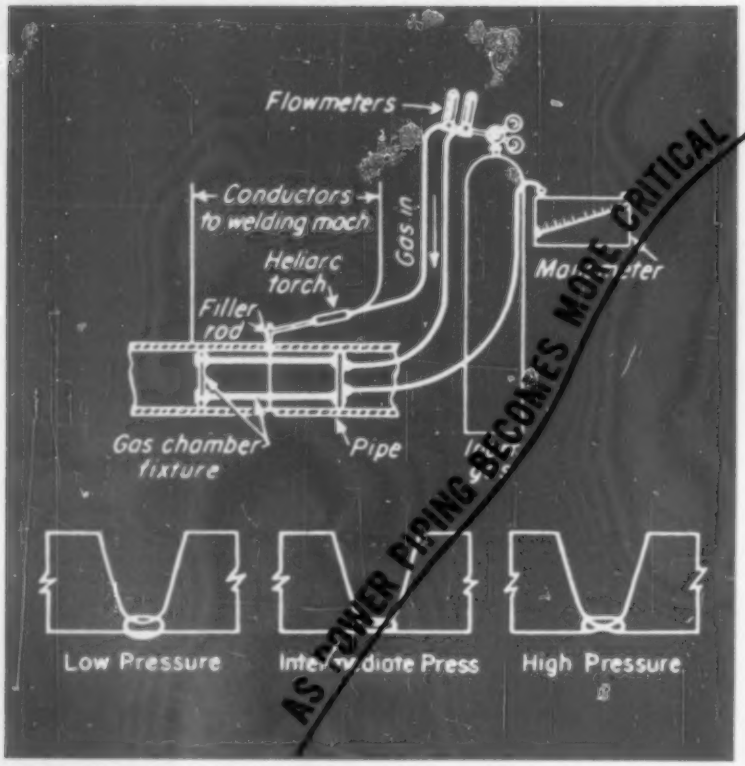

KELLOGG'S FIELD WELDING TECHNIQUES KEEP PACE

With main and reheat steam piping for steam-electric power plants becoming heavier and more difficult to handle because of increasing wall thicknesses, more and more of the welding previously done in fabricators' shops must be handled in the field. This, coupled with the need for still better welding techniques to combat higher operating pressures and temperatures, demands even higher standards of design and workmanship to compensate for the less favorable conditions often encountered in the field.

One way in which M. W. Kellogg sets the pace in field fabrication is with K-Weld*—Kellogg's unique inert gas shielded technique of arc welding. With K-Weld, complete penetration and a highly uniform internal contour are assured without the use of backing rings. Incorporating a Kellogg development which controls internal gas pressure and shape of the interior weld surface automatically, K-Weld is recognized as the ultimate in welding techniques for any type or size of alloy piping—both for shop and field fabrication.

A 12-page booklet, "For The Modern Central Power Station," describes K-Weld and other M. W. Kellogg facilities for the design, fabrication, installation, and testing of main and reheat steam piping.

K-Weld root bead is laid while the pipe interior is under controlled inert gas pressure in the gas chamber fixture. Diagram at top of page shows detail of this portable gas chamber fixture and how interior weld surface is controlled by varying pressure.

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POWER PIPING—THE VITAL LINK

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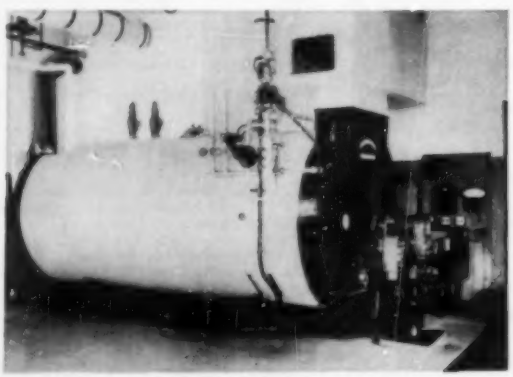

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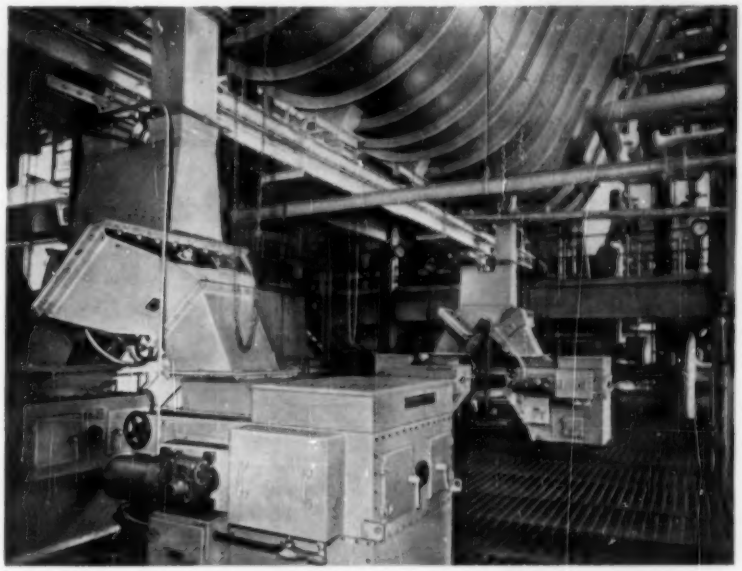

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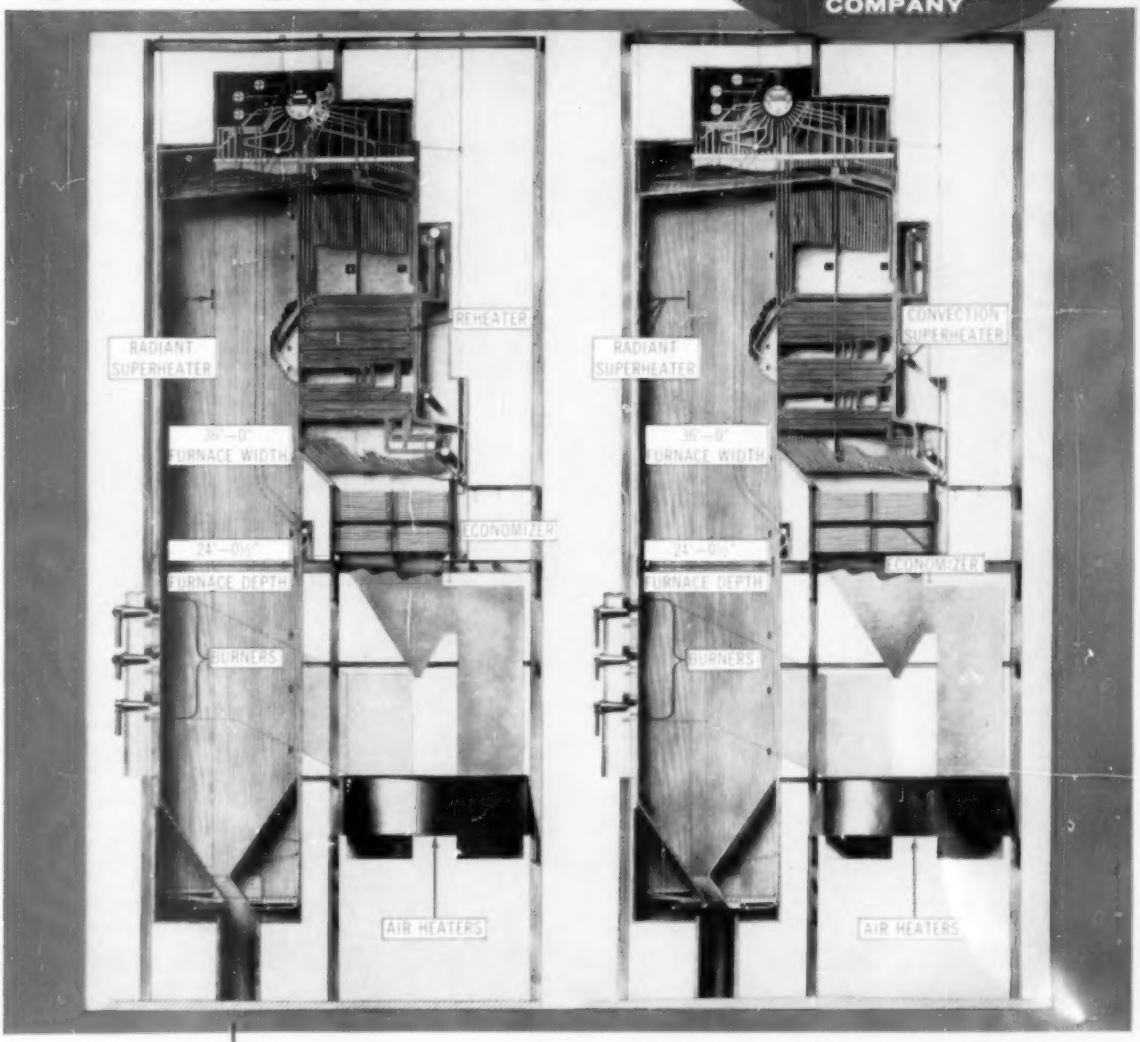

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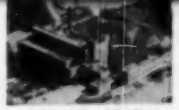

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piping specialist in Power Plant Construction

If you are concerned with the construction of a modern power plant, you realize the absolute need for specialization in all phases of the work. Particularly is this true of the fabrication and installation of the intricate piping which such a project requires. Only a specialist can provide the best in piping; that is, piping which is custom fabricated, properly installed, safely and economically designed for your specific needs. Shaw is such a specialist, qualified through years of experience to fabricate and erect power plant piping for any pressure and any temperature you require. Since 1893, Shaw has devoted its resources, its talents and its energies to this kind of specialization. That's why we say—if your operations depend on piping, you can depend on Shaw.

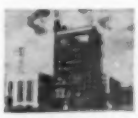
Shown here—and the names included are foremost in the industry—are some of the many power plants in which the piping is Shaw-fabricated.

Fla. Power & Light Co.
Indian River Station

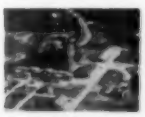
Ohio Power Company
Philo Station, Unit 6

Ind.-Ky. Electric Corp.
Clifty Cr. Sta., Units 1-6

Houston Lighting & Pr. Co.
Greens Bayou Station



Houston Lighting & Pr. Co.
Deepwater Station, Unit 7



Houston Lighting & Pr. Co.
Webster Station

Houston Lighting & Pr. Co.
Sam Bertron Station

Ohio Power Company
Muskingum R. St., Units 1-2

Appalachian Elec. Power Co.
and Ohio Power Company
Philip Sporn Plant

BENJAMIN F.

SHAW

COMPANY

Main Offices and Plant: Wilmington, Delaware

Piping Fabrication and Installation Since 1893